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Technical Report

October 1977

Upgrading Basements for Combined Nuclear Weapons Effects: Predesigned Expedient Options

For:

DEFENSE CIVIL PREPAREDNESS AGENCY
WASHINGTON, D.C. 20301

Contract No. DCPA01-76-C-0315
DCPA Work Unit 1155C

SRI Project 5622

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UPGRADING BASEMENTS FOR COMBINED NUCLEAR WEAPONS EFFECTS: PREDESIGNED EXPEDIENT OPTIONS (UNCLASSIFIED)

By: H. L. Murphy

SRI International (formerly Stanford Research Institute)
Menlo Park, California 94025, October 1977, 200 pages
Contract No. DCPA01-76-C-0315, DCPA Work Unit 1155C

This document continues the phase 1 work reported in AD-A030 762. That

This report is on a continuation of work under a preceding (first-phase) contract concerned with ~~the following:~~ (1) evaluation of a few specific structures, selected in consultation with the Contracting Officer's Technical Representative, DCPA; and (2) devising expedient options for upgrading their structural resistance to blast. The new work was not restricted to expedient options using only indigenous materials and labor, but could also include predesigned options, stored materials, and pre-arrangements for construction trade specialists. The work was to: cover specific "how-to-do-it" applications to be crisis-implemented in a 2- to 3-day period; include quick, inexpensive closure options; and, provide for critical workers remaining behind in "risk areas," plus check of the options' potential for CRP implementation ("host areas"). All applications are to basements, as defined in the first-phase report.*

was

The second-phase work reported includes: This report includes appendices on:

1. An appendix on predesigns and fabrication of plywood stressed-skin panels (PSSPs). Five kinds of commonly available plywood sheets in four nominal thicknesses, 1/2" to 1-1/8" (13 to 29 mm), were considered in combinations with two strengths of stringers (2x4s to 2x8s) at 4 to 9 stringers per 48-in. (1.22 m) wide PSSP. Included are a complete design procedure, computer program listing (BASIC), data on 628 predesigns, and design tables for 2- to 12-ft spans.

2. An appendix on a design procedure for PSSPs used as intermediate (beam-column) supports for beams/girders in the floor over a potential basement shelter. Future work will use the design procedure, plus how-to-do-it evaluation techniques (if such can be developed), to furnish information suitable for use directly by semi-skilled artisans (carpentry).

3. An appendix on using plywood panels by developing a design procedure for their use alone as closures in potential basement shelters. Predesigns have been calculated and development of user tables completed.

4. An appendix reprinted from an earlier report and expanded through preparation of an Addendum that provides simplified charts for use on aperture closures of "2-by" materials (flatwise, plus edgewise for 2x3s to 2x8s† - all in two strength value ranges), again for use by a the semi-skilled artisan (carpentry); and

5. An appendix covering typical availability of wood and plywood in local lumberyards, plus detailed data on species, sizes, stress grading and some grades.

6. A report main body that is rather brief, confining itself to the quickie design charts and a sort of road-map through the appendices, all aimed at the potential user, a semi-skilled artisan, preferably in carpentry, that might be called on to quickly construct the predesigned items for use in converting an existing basement into potential shelter.

Further work is needed in this research area, most especially in this wood use area and on tests to determine resistance behavior through the full range of loadings to collapse - of PSSPs, plywood panels and wood beams. Close collaboration between analytical research and tests projects is needed.

The Introduction section and Appendix C were prepared by a colleague, E. E. Pickering, Sr. Civil Engineer, whose efforts are gratefully acknowledged.

* Murphy, H.L., C.K.Wiehle and E.E.Pickering, Upgrading Basements for Combined Nuclear Weapons Effects: Expedient Options, SRI International (formerly Stanford Research Institute) Technical Report, for U.S. Defense Civil Preparedness Agency, May 1976. (AD-A030 762)

† Nominal cross-section dimensions (38x64 to 38x184 mm, actual dimensions).

Menlo Park, California 94025

Technical Report *October 1977*

Summary

Upgrading Basements for Combined Nuclear Weapons Effects: Predesigned Expedient Options

By: H. L. MURPHY
Sr. Civil Engineer

For:

DEFENSE CIVIL PREPAREDNESS AGENCY
WASHINGTON, D.C. 20301

Contract No. DCPA01-76-C-0315
DCPA Work Unit 1155C

SRI Project 5622

DCPA Review Notice

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SUMMARY

This report is on a continuation of work under an immediately preceding (first-phase) contract briefly described as concerned with ~~the~~ following: (1) evaluation of a few specific structures, selected in consultation with the Contracting Officer's Technical Representative (COTR), DCPA; and (2) devising expedient options for upgrading their structural resistance to blast. The (second-phase) new work was not restricted to expedient options using only indigenous materials and labor, but could also include engineered (i.e., predesigned) options, stored materials, and even pre-arrangements for construction trade specialists if needed. Both the preceding and new work were to: include but not be restricted to NSS structures; cover specific "how-to-do-it" applications for a variety of cases that can be crisis-implemented (say, in a 2- to 3-day period); include quick, inexpensive closure options; consider both open and closed shelter modes; and, provide for critical workers who must remain behind in "risk areas," but the options were to be also investigated for their potential for crisis relocation plan (CRP) implementation ("host areas") in crisis circumstances. All applications are to basements, which are defined in the report on the first-phase work.* The essential emphases on the new work were: the provision of strength/member size data to accompany schemes (alone) presented in the first-phase report; opening the work to consider engineered options instead of being restricted to expedient options as before; and, design review strength evaluations, rather than general use of the detailed existing structures evaluation procedures that are too expensive in computer and professional time.

The second-phase work reported herein includes:

1. An appendix (A1) on predesigns and fabrication of plywood stressed-skin panels (PSSPs). Five kinds of commonly available plywood sheets in four nominal thicknesses, 1/2" to 1-1/8" (13 to 29 mm), were considered in various combinations with two strength levels of stringers (2x4s, 2x6s and 2x8s) at 4, 5, 7 and 9 stringers per 48-in. (1.22 m) wide PSSP. A complete design procedure and listed computer program (Dartmouth BASIC) are included, as are data on 628 PSSP predesigns, used to produce tables of design solutions covering clear spans of 2 to 12 ft.

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* Murphy, H.L., C.K. Wiehle and E.E. Pickering, Upgrading Basements for Combined Nuclear Weapons Effects: Expedient Options, SRI International (formerly Stanford Research Institute) Technical Report, for U.S. Defense Civil Preparedness Agency, May 1976. (AD-A030 762)

2. An appendix (A2) providing a design procedure for PSSPs to be used as intermediate (beam-column) supports for beams/girders in the floor over a potential basement shelter. Future work will use the design procedure, plus how-to-do-it evaluation techniques (if such can be developed), to furnish information suitable for use directly by semi-skilled artisans (carpentry) on adding supports to existing basement cover slabs.

3. An appendix (A3) that completes the work using plywood panels by developing a design procedure for their use alone as closures over the smaller of the apertures found in potential basement shelters. Predesigns have been calculated in sufficient number to allow development of user tables, as was done for PSSP use as closures (paragraph 1 above).

4. An appendix (B) reprinted from an earlier report and expanded through preparation of an Addendum that provides simplified charts for use on aperture closures of "2-by" materials (flatwise, plus edgewise for 2x3s, 2x4s, 2x6s and 2x8s* - all in two strength value ranges), again for use by the semi-skilled artisan (carpentry).

5. An appendix (C) covering typical availability of wood and plywood in local lumberyards. Detailed data on species, sizes, stress grading and some grades, as well as availability, are reported.

6. A report main body that is rather brief, confining itself to the quickie design charts and a sort of road-map through the appendices, all aimed at the potential user, a semi-skilled artisan, preferably in carpentry, that might be called on to quickly construct the predesigned items for use in converting an existing basement into potential shelter.

Further Work

Further work is needed in this research area, most especially in this wood use area and on tests to determine resistance behavior through the full range of loadings to collapse - of PSSPs, plywood panels and wood beams. Close collaboration between an analytical research project, such as this one, and a tests project would greatly strengthen the work of both.

There are Further Work sections in each of Appendices A1, A2 and A3 - the last section in each case - to supplement the comments above.

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* Nominal cross-section dimensions (38x64, 38x89, 38x140 and 38x184 mm, actual dimensions).

Acknowledgments

Through suggestions and guidance, the technical help of G. N. Sisson and M. A. Pachuta, U.S. Defense Civil Preparedness Agency, was freely given and is gratefully acknowledged; similarly acknowledged is the work of a colleague, E. E. Pickering, Sr. Civil Engineer, in contributing the Introduction section and Appendix C, and the considerable assistance readily given by the staff and Head (the late J. M. "Mike" Carney, P.E., and his successor, Wm. A. Baker, P.E.), Engineering Service, Applied Research Department, American Plywood Association, Tacoma, Washington 98401.

Note

Every effort has been made to ensure the accuracy of all guidance and programs included herein. However, no warranty, expressed or implied, is made as to the recommended procedures or programs. The reader-user is expected to make the final evaluation as to the usefulness of all material contained herein. Recommendations made herein should not be substituted for the knowledge, experience, and judgment of the professional engineer or architect, but should be treated as guidance for consideration by the professional, regarding the best method of achieving specific design goals.

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STANFORD RESEARCH INSTITUTE
Menlo Park, California 94025 · U.S.A.

Technical Report *October 1977*

Upgrading Basements for Combined Nuclear Weapons Effects: Predesigned Expedient Options

By: H. L. MURPHY
Sr. Civil Engineer

For:

DEFENSE CIVIL PREPAREDNESS AGENCY
WASHINGTON, D.C. 20301

Contract No. DCPA01-76-C-0315
DCPA Work Unit 1155C

SRI Project 5622

Approved for public release; distribution unlimited.

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This report has been reviewed in the Defense Civil Preparedness Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Defense Civil Preparedness Agency.

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Introduction*

This report covers the results of a two-phased project† with the overall objective of developing a set of expedient and engineered techniques for upgrading the air blast and related effects resistance potential of basements in existing buildings - for use by personnel required to remain in risk areas during a strategic population relocation. The techniques are also applicable for general civil defense shelter purposes, including crisis relocation areas.

Because of their inherent shelter potential, basements of substantial buildings having a concrete slab first floor (supported by either steel or reinforced concrete beam-girder-column systems) are the natural choice for relatively high degrees of protection. The first floor (floor over basement) concrete slab ordinarily has a rather high degree of air blast resistance, because for normal use it must withstand individual point loads, as well as general area loads. The supporting beam and girder system becomes progressively weaker (usually in that order), however, as the tributary areas served increase in size and thus the effect of normal use point loads decreases for the heavier supporting members. Columns may or may not be relatively weaker depending on the height of the building. It is frequently found that the first floor slab itself will resist about 10 psi (69 kPa) of "side-on" air blast pressure or more, but that this potential is degraded rather seriously by weaker beams and girders, and sometimes columns. In addition most basements have exterior openings, and all have interior openings, permitting air blast to enter (assuming that the air blast wave passes through or destroys the building above the basement in the latter case). Thus, the general principle to be followed is to exploit the relatively high floor slab resistance through closing openings and applying strengthening measures to the other portions of the first floor and possibly basement column systems. If the first floor slab does not have an acceptable level of inherent blast resistance, the basement should not be considered for shelter purposes, at least in the general case.

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* Prepared by a colleague, E. E. Pickering, Sr. Civil Engineer

† Some revisions and additions accomplished under a third phase (Contract DCPA01-77-C-0227) are included herein; affected pages show 2/78 in the lower right corner.

The measures available for upgrading existing basement space for shelter purposes are categorized as either "expedient" or "engineered." Expedient measures are those which can be accomplished in a relatively short period of time (say two to three days) during a crisis build-up period by building occupants using readily available materials. Expedient measures may be pre-engineered with resulting designs distributed in advance in "how-to-do-it" drawings and instructions. Engineered measures are also those requiring longer periods of time and the services of professional engineers for evaluation and design, perhaps tailored to a specific building or a specific type of building.

Upgrading measures considered include prevention of air blast entry into the shelter space, reduction of air blast loading on exposed areas, strengthening of floor system structural members, provision of debris protection, provision of "last resort" shelter in case of floor system collapse, and other protective measures. Both closed and open shelter situations were considered as were post-attack considerations.

For the expedient case, the most common vulnerability problems were examined and principles of protection given. Specific building features requiring protection are illustrated and suitable methods of protection and materials are presented. The degree of protection afforded by the various methods and materials are given. Suggested local sources of materials and required tools are also given. The expedient section is prepared in "how-to-do-it" illustrative manner so as to permit ready application by non-engineer building occupants and other untrained personnel.

For the engineered case, the air blast resistance characteristics of suitable basements in existing buildings are described along with upgrading principles and techniques. Methods of evaluating individual buildings for basic first floor system air blast resistance are discussed. Upgrading design guidance for various building features is given. Specific detailed evaluation and design procedures for the more complex upgrading problems are given in appendices. Several examples of existing buildings are also given, with basement upgrading measures applied.

It is intended that this report, together with the first-phase report,[1*] serve as a basic reference and guidance for civil defense planners, building owners, occupants charged with upgrading shelter space for themselves, engineering enterprises, and others concerned with the air blast upgrading of existing buildings before or during a strategic population relocation, or other civil defense shelter program. The information contained herein will also be useful for expedient upgrading, on an opportunity basis, of buildings used for temporary shelter in the population relocation or "host" areas.

Many of the matters mentioned above were covered in the first-phase report[1] for which an overview is provided by a listing of that report's Contents, Table and Figures sections; see Table 1 below. Figures 1 through 11 of the earlier report provide schematics or concepts for closures and structural strengthening; the second-phase work reported below includes engineered/predesigned data for use in closures and strengthening.

The remainder of this report's main body is devoted to the results of the second-phase work, hopefully aimed, in terms of brevity and language, at such non-engineers as artisans at least semi-skilled in carpentry.

For technical readers such as civil engineers and architects interested in strengthening of basements for combined nuclear weapons effects shelter, recommended reading includes the Appendices herein plus Reference 1 for existing basements, and References 2 and 3 for basements under design or planning.

---

* Superscript numerals are related to the References list at the end of this report's main body; each appendix as well has its References list.

Table 1 CONTENTS, TABLE AND REFERENCES LISTS FROM REFERENCE 1

CONTENTS

Table 1 (continued)

Table 1 (concluded)

TABLE

FIGURES

Wood Availability and Use

Appendix C, Typical Stockage - Local Lumberyards, is short and is recommended for complete reading by readers interested in using any of the results reported below.

Specifically, the predesigns reported on below used generally available stress graded lumber in one relatively strong and one relatively weak grade and species for each of two size ranges - one pair of grades for 2x3s* and 2x4s (Light Framing, Construction grade for strong and Standard grade for weak) and one pair for 2x6s and 2x8s (Joists and Planks, Select Structural No. 1 grade for strong and No. 2 for weak). These choices are shown in Table 1B, Appendix C, complete with the predesigns' stresses used below and underlined in that Table. Tables 1A and 2, Appendix C, show the complete list from which the grade choices were made.

Lumberyards have shirt-pocket size booklets (list on page C-2, Appendix C) giving stress grading data by lumber kind, type and size. In any case, try to use construction grade or stress-graded wood members; if stress data is unknown, simply use the charts that follow and choose those calling for "lower strength stringers."

For plywoods, the predesigns used primarily plywood grade Underlayment Interior (American Plywood Association (APA)) in Species Groups (of both face plies) #1 and #3, but the results also cover plywood grades Underlayment Exterior (APA), C-D Interior (APA), and C-C Exterior (APA), all in Species Groups #1 and #3; *nominal thicknesses* used were 1/2", 5/8" and 3/4". Additionally, plywood grade 2.4.1 Interior (APA), manufactured only in Species Group #1,† was used in 1-1/8" nominal thickness, both alone and in combination with some of the thinner plywood grades just mentioned. All plywood grades used in predesigns are the most plentiful and were assumed to be planned for use under dry conditions (equilibrium moisture content less than 16%).‡

It is recommended that the stress graded lumber user consider obtaining a copy of Reference 4, at least the Table 1 Supplement thereto; similarly but for plywood, Reference 5.

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* Nominal English and actual SI (metric) equivalents for all dimensions used in this and the next sections are shown in Figures 5-9, Appendix A-1, and Figures B-1, Appendix B, and in most cases at point of use.

† Actually in Groups 1-3, but see footnote * on page A1-31.

‡ If dry conditions do not apply, all plywood must have "Exterior Glue" (so stamped); blast resistance shown in Table 2 would be reduced about 50% (conservatively; full redesigns are needed for a better estimate).

Plywood Stressed-Skin Panels (Two-Sided)* as Closures

Appendix A1, Plywood Stressed-Skin Panels (Two-Sided Only) as Closures - Design and Fabrication, includes a detailed treatment of the subject, aimed at the designer (engineer or architect); certain sections would be, however, of interest to the artisan reader, who might choose to gain an overview of Appendix A1 through use of its lists of Contents, Tables and Figures (pages A1-iii through -v).

Lumber ("2-by") sizes and grades considered for use in building PSSPs are discussed in the preceding section, as are plywood grades and nominal thicknesses. Figure 1 shows a cutaway perspective view of a 4-stringer PSSP, which also illustrates both continuous and non-continuous headers, as well as splice-plate installation. The latter should have little use herein, because closures are not expected to be needed in lengths longer than the 8-ft and sometimes 12-ft (2.44 and 3.66 m) that are available in plywood stocks of lumberyards. Another view (this one dimensioned) of a similar PSSP is shown by Figure 1A of Appendix A1. Both views show PSSPs with one outside stringer inset 1" (25 mm) and the other outside stringer projecting 3/4" (19 mm) so as to provide tongue-and-groove behavior among side-by-side panels; such detailing is perhaps impractical for the rapid construction of expedient option closures during a one- to three-day warning period, and such detailing is not recommended for other (mostly strength) reasons as well.

To obtain the strength benefits of stressed-skin structural behavior,† PSSPs are built with the plywood face plies running parallel to the stringers, which must be joined to the plywood by either nailed-glued or pressure-glued construction (the latter is better so should be used if facilities are available therefor). See the Fabrication section, Appendix A1, for details.

Figure 5 (6 for metric) and 7-9 (both English and metric) of Appendix A1 bring together the results of more than a hundred PSSP designs, but an improved presentation was developed for this section of the report - Table 2 (following) presents 124 designs in a form for direct reading:

* Abbreviated as PSSPs herein.

† See footnote ‡ on preceding page.

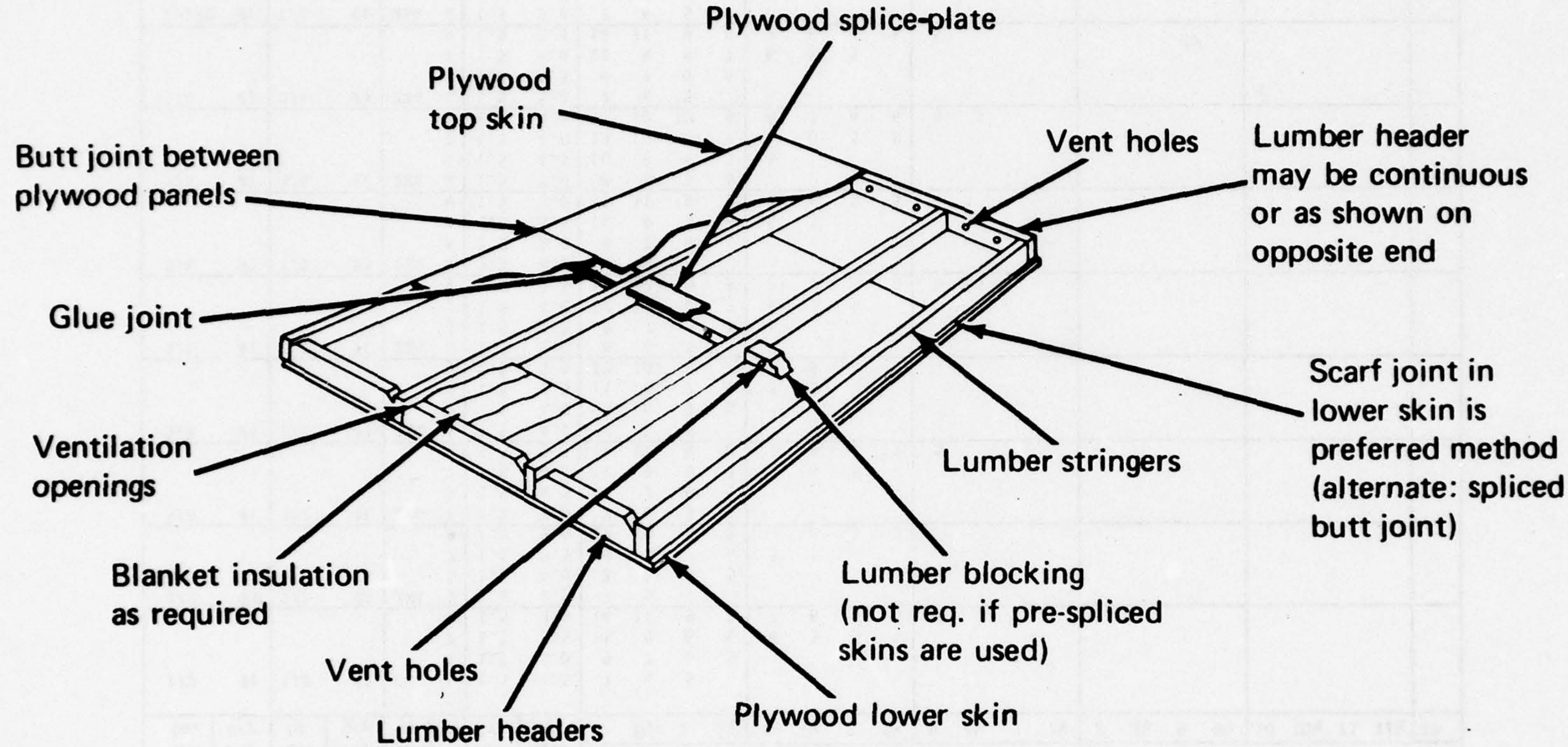

FIGURE 1 TYPICAL TWO-SIDED PLYWOOD STRESSED-SKIN PANEL[5]

Table 2A PSSP DESIGNS FOR LOWER STRENGTH STRINGERS (F_v = 280 psi)

Panel Width: 48 in.

TOP SKIN		BOT. SKIN		STRNGRS		REQD. BEAR. EACH END		(FREE FIELD, SIDE-ON, LONG DURATION) PEAK AIR BLAST OVERPRESSURE psi VS. CLEAR SPAN																				
Nom. Th. in.	Face Ply Grp	Nom. Th. in.	Face Ply Grp	Nom. Size in.	No.	Ply. Bot. Skin in.	Str-ngrs in.	Clear Span, ft																				
								2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	9½	10	10½	11	11½	12
1/2	#1	1/2	#1	2X4	4	1.5	4.5	7	6	5																		
					5	1.5	4.0	9	7	6	5																	
					7	1.5	3.5	11	9	8	6	6	5	5														
					9	1.5	3.5	14	11	9	8	7	6	6	5	5												
1/2	#3	1/2	#3	2X4	4	1.5	4.5	7	5																			
					5	1.5	4.0	8	6	5	5																	
					7	1.5	3.5	10	8	7	6	5	5															
					9	1.5	3.0	12	10	8	7	6	6	5	5													
5/8	#1	1/2	#1	2X4	4	1.5	5.0	7	6	5																		
					5	1.5	4.5	9	7	6	5																	
					7	1.5	4.0	12	9	8	7	6	5	5														
					9	1.5	3.5	14	11	9	8	7	6	6	5	5												
5/8	#3	1/2	#3	2X4	4	1.5	4.5	7	5	5																		
					5	1.5	4.0	8	6	5	5																	
					7	1.5	3.5	11	8	7	6	5	5															
					9	1.5	3.0	13	10	8	7	6	6	5	5													
3/4	#1	1/2	#1	2X4	4	1.5	5.0	8	6	5																		
					5	1.5	4.5	9	7	6	5	5																
					7	1.5	4.0	12	10	8	7	6	5	5														
					9	1.5	3.5	15	12	10	8	7	7	6	5	5	5											
3/4	#3	1/2	#3	2X4	4	1.5	4.5	7	6	5																		
					5	1.5	4.0	8	7	6	5																	
					7	1.5	3.5	11	9	7	6	6	5															
					9	1.5	3.5	13	11	9	8	7	6	5	5													
3/4	#1	3/4	#1	2X4	4	1.5	5.0	8	6	5	5																	
					5	1.5	4.5	10	8	6	5	5																
					7	1.5	4.0	13	10	8	7	6	6	5	5													
					9	1.5	4.0	15	12	10	9	8	7	6	6	5	5											
3/4	#3	3/4	#3	2X4	4	1.5	5.0	7	6	5																		
					5	1.5	4.5	9	7	6	5																	
					7	1.5	4.0	12	9	8	7	6	5	5														
					9	1.5	3.5	14	11	9	8	7	6	6	5	5												
1-1/8	#1	1/2	#1	2X4	4	1.5	5.0	7	6	5																		
					5	1.5	4.5	9	8	6	5	5																
					7	1.5	4.5	13	11	9	8	7	6	5	5													
					9	1.5	4.0	16	13	11	9	8	7	7	6	5	5	5										
1-1/8	#1	1/2	#3	2X4	4	1.5	4.5	7	6	5																		
					5	1.5	4.5	9	7	6	5	5																
					7	1.5	4.5	13	11	9	8	7	6	5	5													
					9	1.5	4.0	16	13	11	9	8	7	6	6	5	5	5										

Table 2A (continued)

1-1/8	#1	3/4	#1	2X4	4	1.5	5.0	8	6	5															
					5	1.5	5.0	10	8	7	6	5													
					7	1.5	4.5	14	11	9	8	7	6	6	5	5									
					9	1.5	4.0	17	14	11	10	9	8	7	6	6	5	5	5						
1-1/8	#1	3/4	#3	2X4	4	1.5	5.0	7	6	5															
					5	1.5	4.5	10	8	6	5	5													
					7	1.5	4.5	14	11	9	8	7	6	5	5	5									
					9	1.5	4.0	17	13	11	9	8	7	7	6	6	5	5							
1-1/8	#1	1-1/8	#1	2X4	4	1.5	5.5	9	7	6	5														
					5	1.5	5.0	11	9	7	6	5	5												
					7	1.5	5.0	15	12	10	9	7	7	6	5	5	5								
					9	1.5	4.5	18	15	12	10	9	8	7	7	6	6	5	5	5					
1/2	#1	1/2	#1	2X6	4	1.5	7.5	11	9	8	7	6	5	5											
					5	1.5	6.5	14	11	9	8	7	6	6	5	5									
					7	1.5	6.0	19	15	12	11	9	8	7	7	6	6	5	5	5					
					9	1.5	5.5	23	19	15	13	12	10	9	8	8	7	7	6	6	5	5	5	5	
1/2	#3	1/2	#3	2X6	4	1.5	7.0	11	9	7	6	5	5												
					5	1.5	6.5	14	11	9	8	7	6	5	5	5									
					7	1.5	5.5	18	14	12	10	9	8	7	6	6	5	5	5						
					9	2.0	5.5	22	17	15	12	11	10	9	8	7	7	6	6	5	5	5			
5/8	#1	1/2	#1	2X6	4	1.5	7.5	12	9	8	7	6	5	5											
					5	1.5	7.0	14	11	9	8	7	6	6	5	5									
					7	1.5	6.0	19	15	13	11	9	8	8	7	6	6	5	5	5					
					9	1.5	5.5	23	19	16	13	12	10	9	9	8	7	7	6	6	6	5	5	5	
5/8	#3	1/2	#3	2X6	4	1.5	7.0	11	9	7	6	6	5												
					5	1.5	6.5	14	11	9	8	7	6	6	5	5									
					7	1.5	6.0	18	14	12	10	9	8	7	6	6	5	5	5						
					9	2.0	5.5	22	18	15	13	11	10	9	8	7	7	6	6	6	5	5			
3/4	#1	1/2	#1	2X6	4	1.5	7.5	12	10	8	7	6	5	5											
					5	1.5	7.0	15	12	10	8	7	6	6	5	5									
					7	1.5	6.5	20	16	13	11	10	9	8	7	7	6	6	5	5	5				
					9	1.5	6.0	24	20	16	14	12	11	10	9	8	8	7	7	6	6	5	5	5	5
3/4	#3	1/2	#3	2X6	4	1.5	7.5	11	9	8	7	6	5	5											
					5	1.5	7.0	14	11	10	8	7	6	6	5	5									
					7	1.5	6.0	19	15	12	11	9	8	7	7	6	6	5	5	5					
					9	2.0	5.5	23	18	15	13	11	10	9	8	8	7	7	6	6	5	5			
3/4	#1	3/4	#1	2X6	4	1.5	8.0	12	10	8	7	6	5	5											
					5	1.5	7.0	15	12	10	8	7	7	6	5	5	5								
					7	1.5	6.5	20	16	13	11	10	9	8	7	7	6	6	5	5	5				
					9	1.5	6.0	25	20	16	14	12	11	10	9	8	8	7	7	6	6	5	5	5	5
3/4	#3	3/4	#3	2X6	4	1.5	7.5	12	9	8	7	6	5	5											
					5	1.5	7.0	14	12	10	8	7	6	6	5	5									
					7	1.5	6.0	19	15	13	11	9	8	8	7	6	6	5	5	5					
					9	2.0	5.5	23	19	15	13	12	10	9	8	8	7	7	6	6	5	5	5		

Table 2A PSSP DESIGNS FOR LOWER STRENGTH STRINGERS (F_V = 280 psi) (concluded)

Panel Width: 48 in.

TOP SKIN Nom. Th. in.	TOP SKIN Face Ply Grp	BOT. SKIN Nom. Th. in.	BOT. SKIN Face Ply Grp	STRNGRS Nom. Size in.	STRNGRS No.	REQD. BEAR. EACH END Ply. Bot. Skin in.	REQD. BEAR. EACH END Str-ngrs in.	(FREE FIELD, SIDE-ON, LONG DURATION) PEAK AIR BLAST OVERPRESSURE psi VS. CLEAR SPAN — Clear Span, ft: 2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	9½	10	10½	11	11½	12
1-1/8	#1	1/2	#1	2X6	4	1.5	7.5	12	9	8	7	6	5	5														
					5	1.5	7.0	15	12	10	8	7	7	6	5	5	5											
					7	1.5	7.0	21	17	14	12	11	10	9	8	7	7	6	6	5	5	5	5					
					9	1.5	6.5	27	21	18	15	13	12	11	10	9	8	8	7	7	6	6	6	5	5	5	5	
1-1/8	#1	1/2	#3	2X6	4	1.5	7.0	11	9	7	6	5	5															
					5	1.5	7.0	15	12	10	8	7	6	6	5	5												
					7	2.0	7.0	22	17	15	12	11	10	9	8	7	7	6	6	5	5	5	5					
					9	2.0	6.5	27	22	18	15	14	12	11	10	9	8	8	7	7	6	6	6	5	5	5		
1-1/8	#1	3/4	#1	2X6	4	1.5	8.0	12	10	8	7	6	5	5														
					5	1.5	7.5	15	12	10	9	8	7	6	6	5	5											
					7	1.5	7.0	22	17	14	12	11	10	9	8	7	7	6	6	5	5	5	5					
					9	1.5	6.5	27	22	18	15	13	12	11	10	9	8	8	7	7	6	6	6	5	5	5	5	
1-1/8	#1	3/4	#3	2X6	4	1.5	7.5	11	9	8	7	6	5	5														
					5	1.5	7.0	15	12	10	9	7	7	6	5	5	5											
					7	2.0	7.0	22	18	15	13	11	10	9	8	7	7	6	6	5	5	5	5					
					9	2.0	6.5	27	22	18	16	14	12	11	10	9	8	8	7	7	6	6	6	5	5	5	5	
1-1/8	#1	1-1/8	#1	2X6	4	1.5	8.5	13	11	9	8	7	6	5	5													
					5	1.5	8.0	16	13	11	9	8	7	6	6	5	5	5										
					7	1.5	7.0	22	18	15	13	11	10	9	8	7	7	6	6	5	5	5	5					
					9	1.5	6.5	27	22	18	16	14	12	11	10	9	8	8	7	7	6	6	6	5	5	5	5	5
1-1/8	#1	1/2	#1	2X8	4	1.5	10.0	16	12	10	9	8	7	6	6	5	5											
					5	1.5	10.0	20	16	14	12	10	9	8	7	7	6	6	5	5	5	5						
					7	1.5	9.5	30	24	20	17	15	13	12	11	10	9	9	8	8	7	7	6	6	6	5	5	5
					9	2.0	9.0	38	30	25	22	19	17	15	14	13	12	11	10	10	9	8	8	8	7	7	7	6
1-1/8	#1	1/2	#3	2X8	4	1.5	9.5	15	12	10	8	7	7	6	5	5	5											
					5	1.5	10.0	20	16	13	12	10	9	8	7	7	6	6	5	5	5							
					7	2.5	10.0	31	25	21	18	16	14	13	11	10	10	9	8	8	7	7	7	6	6	6	5	5
					9	3.0	9.5	39	31	26	22	20	17	16	14	13	12	11	10	10	9	9	8	8	7	7	6	6
1-1/8	#1	3/4	#1	2X8	4	1.5	10.5	16	13	11	9	8	7	7	6	5	5	5										
					5	1.5	10.0	21	17	14	12	10	9	8	8	7	6	6	6	5	5	5						
					7	1.5	9.5	30	24	20	17	15	13	12	11	10	9	9	8	7	7	7	6	6	6	5	5	5
					9	2.0	9.0	38	30	25	21	19	17	15	14	13	12	11	10	9	9	8	8	8	7	7	7	6
1-1/8	#1	3/4	#3	2X8	4	1.5	10.0	15	12	10	9	8	7	6	6	5	5											
					5	1.5	10.0	21	16	14	12	10	9	8	7	7	6	6	5	5	5	5						
					7	2.5	10.0	31	25	21	18	15	14	12	11	10	10	9	8	8	7	7	7	6	6	6	5	5
					9	3.0	9.5	39	31	26	22	19	17	16	14	13	12	11	10	10	9	9	8	8	7	7	7	6
1-1/8	#1	1-1/8	#1	2X8	4	1.5	11.0	17	14	12	10	9	8	7	6	6	5	5	5									
					5	1.5	10.5	21	17	14	12	11	9	9	8	7	7	6	6	5	5	5						
					7	1.5	9.5	29	23	20	17	15	13	12	11	10	9	8	8	7	7	7	6	6	6	5	5	5
					9	2.0	9.0	37	30	25	21	19	16	15	13	12	11	11	10	9	9	8	8	7	7	7	6	6

Table 2B PSSP DESIGNS FOR HIGHER STRENGTH STRINGERS (F_v = 380 psi)

Panel Width: 48 in.

TOP SKIN		BOT. SKIN		STRNGRS		REQD. BEAR. EACH END		(FREE FIELD, SIDE-ON, LONG DURATION) PEAK AIR BLAST OVERPRESSURE psi VS. CLEAR SPAN																				
								Clear Span, ft.																				
Nom. Th. in.	Face Ply Grp	Nom. Th. in.	Face Ply Grp	Nom. Size in.	No.	Ply. Bot. Skin in.	Str-ngrs in.	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	9½	10	10½	11	11½	12
1/2	#1	1/2	#1	2X4	4	1.5	3.5	9	7	6	5	5																
					5	1.5	3.5	11	9	7	6	5	5															
					7	1.5	3.0	14	11	9	8	7	6	6	5	5												
					9	1.5	2.5	17	14	11	10	8	8	7	6	6	5	5	5									
1/2	#3	1/2	#3	2X4	4	1.5	3.5	8	7	6	5																	
					5	1.5	3.0	10	8	7	6	5																
					7	1.5	2.5	13	10	8	7	6	6	5	5													
					9	1.5	2.5	15	12	10	9	8	7	6	6	5	5											
5/8	#1	1/2	#1	2X4	4	1.5	3.5	9	7	6	5	5																
					5	1.5	3.5	11	9	7	6	5	5															
					7	1.5	3.0	14	11	10	8	7	6	6	5	5												
					9	1.5	2.5	17	14	11	10	9	8	7	6	6	5	5	5									
5/8	#3	1/2	#3	2X4	4	1.5	3.5	8	7	6	5																	
					5	1.5	3.0	10	8	7	6	5																
					7	1.5	2.5	13	10	9	7	6	6	5	5													
					9	1.5	2.5	15	12	10	9	8	7	6	6	5	5											
3/4	#1	1/2	#1	2X4	4	1.5	3.0	8	6	5	5																	
					5	1.5	3.0	10	8	7	6	5	5															
					7	1.5	3.0	15	12	10	9	8	7	6	5	5	5											
					9	1.5	3.0	18	14	12	10	9	8	7	7	6	6	5	5	5								
3/4	#3	1/2	#3	2X4	4	1.5	3.5	8	7	6	5																	
					5	1.5	3.0	10	8	7	6	5																
					7	1.5	3.0	13	11	9	8	7	6	5	5													
					9	1.5	2.5	16	13	11	9	8	7	6	6	5	5	5										
3/4	#1	3/4	#1	2X4	4	1.5	3.5	8	7	6	5																	
					5	1.5	3.5	11	9	7	6	5	5															
					7	1.5	3.0	16	13	11	9	8	7	6	6	5	5	5										
					9	1.5	3.0	19	15	13	11	10	8	8	7	6	6	5	5	5								
3/4	#3	3/4	#3	2X4	4	1.5	3.5	9	7	6	5	5																
					5	1.5	3.5	11	9	7	6	5	5															
					7	1.5	3.0	14	11	9	8	7	6	6	5	5												
					9	1.5	2.5	17	14	11	10	9	8	7	6	6	5	5										
1-1/8	#1	1/2	#1	2X4	4	1.5	3.0	7	6	5																		
					5	1.5	3.0	10	8	7	6	5	5															
					7	1.5	3.0	16	12	10	9	8	7	6	6	5	5											
					9	1.5	3.0	20	16	14	12	10	9	8	7	7	6	6	5	5	5	5						
1-1/8	#1	1/2	#3	2X4	4	1.5	3.0	7	6	5																		
					5	1.5	3.0	10	8	6	6	5																
					7	1.5	3.0	15	12	10	8	7	7	6	5	5	5											
					9	1.5	3.0	20	16	13	11	10	9	8	7	7	6	6	5	5	5							

Table 2B PSSP DESIGNS FOR HIGHER STRENGTH STRINGERS (F_V = 380 psi) (continued)

Panel Width: 48 in.

TOP SKIN		BOT. SKIN		STRNGRS		REQ'D. BEAR. EACH END		(FREE FIELD, SIDE-ON, LONG DURATION) PEAK AIR BLAST OVERPRESSURE psi VS. CLEAR SPAN																				
								Clear Span, ft																				
Nom. Th. in.	Face Ply Grp	Nom. Th. in.	Face Ply Grp	Nom. Size in.	No.	Ply. Bot. Skin in.	Str-ngrs in.	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	9½	10	10½	11	11½	12
1-1/8	#1	3/4	#1	2X4	4	1.5	3.0	8	6	5	5																	
					5	1.5	3.5	11	9	7	6	5	5															
					7	1.5	3.5	17	13	11	10	8	7	7	6	6	5	5										
					9	1.5	3.0	21	17	14	12	11	9	8	8	7	7	6	6	5	5	5						
1-1/8	#1	3/4	#3	2X4	4	1.5	3.0	7	6	5																		
					5	1.5	3.0	10	8	7	6	5	5															
					7	1.5	3.0	16	12	10	9	8	7	6	6	5	5											
					9	1.5	3.0	20	16	14	12	10	9	8	7	7	6	6	5	5	5							
1-1/8	#1	1-1/8	#1	2X4	4	1.5	3.5	9	7	6	5																	
					5	1.5	3.5	12	10	8	7	6	5	5														
					7	1.5	4.0	19	15	12	11	9	8	7	7	6	6	5	5	5								
					9	1.5	3.5	23	18	15	13	11	10	9	8	8	7	7	6	6	5	5	5					
1/2	#1	1/2	#1	2X6	4	1.5	6.0	15	12	10	8	7	6	6	5	5												
					5	1.5	5.5	18	14	12	10	9	8	7	6	6	5	5	5									
					7	1.5	4.5	24	19	16	13	12	10	9	9	8	7	7	6	6	6	5	5	5				
					9	1.5	4.5	29	23	19	17	15	13	12	11	10	9	8	8	7	7	6	6	6	6	5	5	
1/2	#3	1/2	#3	2X6	4	1.5	5.5	14	11	9	8	7	6	6	5	5												
					5	1.5	5.0	17	14	11	10	8	8	7	6	6	5	5	5									
					7	2.0	4.5	22	18	15	13	11	10	9	8	7	7	6	6	6	5	5	5					
					9	2.5	4.0	28	22	18	16	14	12	11	10	9	9	8	7	7	7	6	5	5				
5/8	#1	1/2	#1	2X6	4	1.5	6.0	15	12	10	8	7	7	6	5	5	5											
					5	1.5	5.5	18	14	12	10	9	8	7	7	6	6	5	5									
					7	1.5	5.0	24	19	16	14	12	11	10	9	8	7	7	6	6	6	5	5	5	5			
					9	1.5	4.5	30	24	20	17	15	13	12	11	10	9	8	8	7	7	7	6	6	5	5	5	
5/8	#3	1/2	#3	2X6	4	1.5	5.5	14	11	9	8	7	6	6	5	5												
					5	1.5	5.0	17	14	12	10	9	8	7	6	6	5	5	5									
					7	2.0	4.5	22	18	15	13	11	10	9	8	7	7	6	6	6	5	5	5					
					9	2.5	4.0	28	22	19	16	14	12	11	10	9	9	8	7	7	7	6	5	5				
3/4	#1	1/2	#1	2X6	4	1.5	5.5	14	11	9	8	7	6	5	5	5												
					5	1.5	5.0	17	14	12	10	9	8	7	6	6	5	5	5									
					7	1.5	5.0	25	20	17	14	12	11	10	9	8	8	7	7	6	6	6	5	5	5	5		
					9	1.5	4.5	31	25	20	18	15	14	12	11	10	9	9	8	8	7	7	6	6	6	5	5	
3/4	#3	1/2	#3	2X6	4	1.5	6.0	15	12	10	8	7	6	6	5	5												
					5	1.5	5.5	18	15	12	10	9	8	7	7	6	6	5	5	5								
					7	2.0	4.5	23	19	16	13	12	10	9	8	8	7	7	6	6	5	5	5					
					9	2.5	4.5	29	23	19	16	14	13	12	10	10	9	8	8	7	7	6	5	5				
3/4	#1	3/4	#1	2X6	4	1.5	5.5	14	12	10	8	7	6	6	5	5												
					5	1.5	5.5	18	14	12	10	9	8	7	7	6	6	5	5									
					7	1.5	5.0	25	20	17	14	13	11	10	9	8	8	7	7	6	6	6	5	5	5	5		
					9	1.5	4.5	31	25	21	18	16	14	12	11	10	10	9	8	8	7	7	7	6	6	5	5	5

Table 2B (concluded)

3/4	#3	3/4	#3	2X6	4	1.5	6.0	15	12	10	8	7	7	6	5	5	5											
					5	1.5	5.5	18	15	12	10	9	8	7	7	6	6	5	5	5								
					7	2.0	4.5	24	19	16	13	12	10	9	9	8	7	7	6	6	6	5	5	5				
					9	2.5	4.5	29	23	19	17	15	13	12	11	10	9	8	8	7	7	6	6	5	5			
1-1/8	#1	1/2	#1	2X6	4	1.5	5.0	12	10	8	7	6	5	5														
					5	1.5	5.0	17	14	12	10	9	8	7	6	6	5	5	5									
					7	1.5	5.5	27	22	18	16	14	12	11	10	9	8	8	7	7	6	6	6	5	5	5	5	
					9	1.5	5.0	34	27	22	19	17	15	13	12	11	10	10	9	8	8	7	7	7	6	6	5	5
1-1/8	#1	1/2	#3	2X6	4	1.5	4.5	12	9	8	7	6	5	5														
					5	1.5	5.0	16	13	11	9	8	7	7	6	5	5	5										
					7	2.0	5.0	26	21	17	15	13	12	10	9	9	8	7	7	6	6	6	5	5	5	5	5	
					9	2.5	5.0	34	27	23	19	17	15	14	12	11	10	10	9	8	8	8	7	7	6	5	5	5
1-1/8	#1	3/4	#1	2X6	4	1.5	5.0	13	10	9	7	6	6	5	5													
					5	1.5	5.5	18	14	12	10	9	8	7	6	6	5	5	5									
					7	1.5	5.5	27	22	18	16	14	12	11	10	9	8	8	7	7	6	6	6	5	5	5	5	5
					9	1.5	5.0	34	27	23	19	17	15	14	12	11	10	10	9	8	8	8	7	7	6	6	6	5
1-1/8	#1	3/4	#3	2X6	4	1.5	5.0	12	10	8	7	6	5	5														
					5	1.5	5.0	17	14	11	10	9	8	7	6	6	5	5	5									
					7	2.0	5.5	27	22	18	15	13	12	11	10	9	8	8	7	7	6	6	6	5	5	5	5	
					9	2.5	5.0	34	27	23	19	17	15	14	12	11	10	10	9	9	8	8	7	7	6	6	5	5
1-1/8	#1	1-1/8	#1	2X6	4	1.5	5.5	14	11	9	8	7	6	6	5	5												
					5	1.5	5.5	19	15	12	11	9	8	7	7	6	6	5	5	5								
					7	1.5	5.5	28	22	19	16	14	12	11	10	9	9	8	7	7	7	6	6	6	5	5	5	5
					9	2.0	5.0	34	28	23	20	17	15	14	13	11	11	10	9	9	8	8	7	7	7	6	6	6
1-1/8	#1	1/2	#1	2X8	4	1.5	6.5	17	14	11	10	8	8	7	6	6	5	5	5									
					5	1.5	7.0	24	19	16	14	12	11	10	9	8	7	7	6	6	6	5	5	5	5			
					7	2.0	7.5	39	31	26	22	20	17	16	14	13	12	11	10	10	9	9	8	8	7	7	7	7
					9	2.5	7.5	49	39	33	28	25	22	20	18	16	15	14	13	12	12	11	10	10	9	9	8	7
1-1/8	#1	1/2	#3	2X8	4	1.5	6.5	16	13	11	9	8	7	6	6	5	5	5										
					5	2.0	7.0	23	19	15	13	12	10	9	8	8	7	7	6	6	5	5	5	5				
					7	3.0	7.5	38	30	25	21	19	17	15	14	13	12	11	10	9	9	8	8	8	7	7	7	6
					9	4.0	7.5	51	40	34	29	25	22	20	18	17	16	14	13	13	12	11	11	10	9	8	8	7
1-1/8	#1	3/4	#1	2X8	4	1.5	7.0	18	14	12	10	9	8	7	6	6	5	5	5									
					5	1.5	7.5	25	20	16	14	12	11	10	9	8	8	7	7	6	6	5	5	5	5			
					7	2.0	7.5	39	31	26	22	19	17	16	14	13	12	11	10	10	9	9	8	8	7	7	7	6
					9	2.5	7.0	49	39	33	28	24	22	20	18	16	15	14	13	12	11	11	10	10	9	9	8	8
1-1/8	#1	3/4	#3	2X8	4	1.5	6.5	17	13	11	9	8	7	7	6	6	5	5										
					5	2.0	7.0	24	19	16	14	12	11	10	9	8	7	7	6	6	6	5	5	5	5			
					7	3.0	7.5	39	31	26	22	19	17	16	14	13	12	11	10	10	9	9	8	8	7	7	7	6
					9	4.0	7.5	50	40	33	29	25	22	20	18	17	15	14	13	13	12	11	11	10	9	9	8	7
1-1/8	#1	1-1/8	#1	2X8	4	1.5	7.5	19	15	13	11	10	9	8	7	6	6	5	5	5	5							
					5	1.5	7.5	26	20	17	15	13	11	10	9	9	8	7	7	6	6	6	5	5	5	5		
					7	2.0	7.5	38	31	26	22	19	17	15	14	13	12	11	10	10	9	9	8	8	7	7	7	6
					9	2.5	7.0	48	39	32	28	24	21	19	18	16	15	14	13	12	11	11	10	10	9	9	8	8

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Columns 1-4 present nominal thickness and Face Ply Species Group for the top and bottom plywood skins of the PSSP designs; columns 5-6 give the nominal size (2x4 to 2x8) and number of stringers (per 48-in. wide PSSP), with the latter showing 4, 5, 7 and 9, but 6 or 8 may be used by taking values (in columns 7 and beyond) between 5-7 and 7-9, respectively; columns 7-8 show the PSSP required bearing length on each end support (in addition to the clear span dimension), in terms of bearing length on the plywood bottom skin and on the stringer bottom edge, respectively (the latter happens to be controlling in all 124 designs); the remaining columns show, for each of the 124 designs, the PSSP's estimated blast overpressure resistance (psi) for clear spans from 2 to 12 ft by ½-ft increments, but omitting any value below 5 psi. In a particular application, the clear span for the blast closure will be known, as will availability (sizes, grades, etc.) of plywood and stringers; from this point one might proceed as follows:

1. Consider that the data presented covers four plywood grades in three nominal thicknesses and two face ply species grades, plus a fifth grade in one nominal thickness and one face ply species;* and the plywood combinations are each used in predesigns with two stringer strengths (termed lower and higher in Tables 2A&B) - all as described in the preceding section, Wood Availability and Use.

2. Consider the data for, say, the 6th PSSP design (with 7 stringers), Table 2: Top and bottom skins nominal thickness are 3/4" and 1/2", respectively, both in #3 Face Ply Species Group, and the 7 (lower strength) stringers are 2x4s (nominal dimensions).

3. Required bearing length at each end of the PSSP, in addition to the clear span length, would be the larger value of Columns 7-8, or 3.5 in.

4. For a clear span of, say, 2½ ft the estimated peak air blast (side-on) overpressure resistance would be 9 psi (Column 10).

5. Equivalent free-field air blast peak overpressure to the 9 psi just found, which is for overpressure when applied side-on, would be 4 psi free-field air blast peak overpressure if applied fully reflected (i.e.,

* Actually in Groups 1-3, but see footnote * on page A1-31.

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head-on); the peak blast pressure felt by the PSSP would be 9 psi in either case, if taxed to its estimated design resistance. The graph on page 6-117, Appendix B (see also the accompanying text under the same "bullet") may be used to find such "side-on" versus "head-on" equivalent free-field air blast peak overpressures, in either English or SI (metric) units (it is sufficiently accurate for purposes herein to use 1 kg/cm^2 = 100 kPa = 100 kN/m^2 in reading the graph).

6. For PSSP widths less than 48 inches (1.219 m): Convert the planned PSSP width and stringer spacing to a 48-in. wide equivalent PSSP; select the equivalent 48-in. PSSP number of stringers so that its stringer spacing is equal to or wider than that in the planned PSSP. Find the applicable overpressure value for the known clear span, as above; such value may be used without reduction for PSSP widths of 24 in. (0.61 m) or more, but it is recommended that it be reduced linearly from 0% to 50% for PSSP widths of 24" to 8" (0.61 to 0.203 m), respectively, with the latter being the narrowest width recommended for use (this recommendation is adapted from Reference 5, page 19). NOTE: Panel width, as used throughout this section, is always measured perpendicular to the span direction of the PSSP.

7. Selection of a particular PSSP design for planned use would probably be by trial-and-check repeated use of Steps 2 through 6 above.

Wood Beams ("2-by's") as Closures

Appendix B, Design of Wood Beams - Simply Supported, is an extract from earlier published reports by the same senior author, as indicated on page B-i of the appendix. It was the basis for developing simplified charts for use in constructing closures over basement apertures, using "2-by's" flatwise, as well as 2x3s, 2x4s, 2x6s and 2x8s edgewise.* Stress graded lumber in one relatively strong and one relatively weak grade and species for each of two size ranges, the same as those described in a section above, Wood Availability and Use, in its second paragraph, were used in preparing the simplified charts; the charts, Figures B-1A and B-1B follow, reproduced from Appendix B ADDENDUM.

The potential user of the following charts is urged to read page B-1, the less-than-a-page total text of the Addendum.

Figure B-1A is for the lower strength "2-by" members; Figure B-1B for the higher. In use, one enters the Figures with the desired clear span (in. or m) known and reads, for each of the member sizes and orientation (flatwise or edgewise) its resistance capacity in terms of air blast peak overpressure (psi) when applied side-on. Conversion to blast resistance when hitting head-on is the same as described under Step 5 in the section on PSSPs just above.

For example, assume a clear span of 110" (2.8 m) and lower strength "2-by's." Entering Figure B-1A with span of 110: Read 11 psi (76 kPa) for a 2x6 (38x140 mm) edgewise, requiring 3.5" (89 mm) bearing length at each end (in addition to the clear span length, of course); also read 19 psi (130 kPa) for a 2x8 (38x184 mm) edgewise, requiring 5½" (140 mm) bearing length at each end.

Attention is invited to the type of construction assumption used for the charts: fourth paragraph of the Addendum text, page B-1. Page B-3 has a **NOTE** important to the Figures B-1 user (a late addition).

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* Actually, these (construction grade) wood members could be any width, not just "2-by", and, except for "2-by's used flatwise," Figures B-1 would still be used for member depths shown (3, 4, 6 and 8 inches).

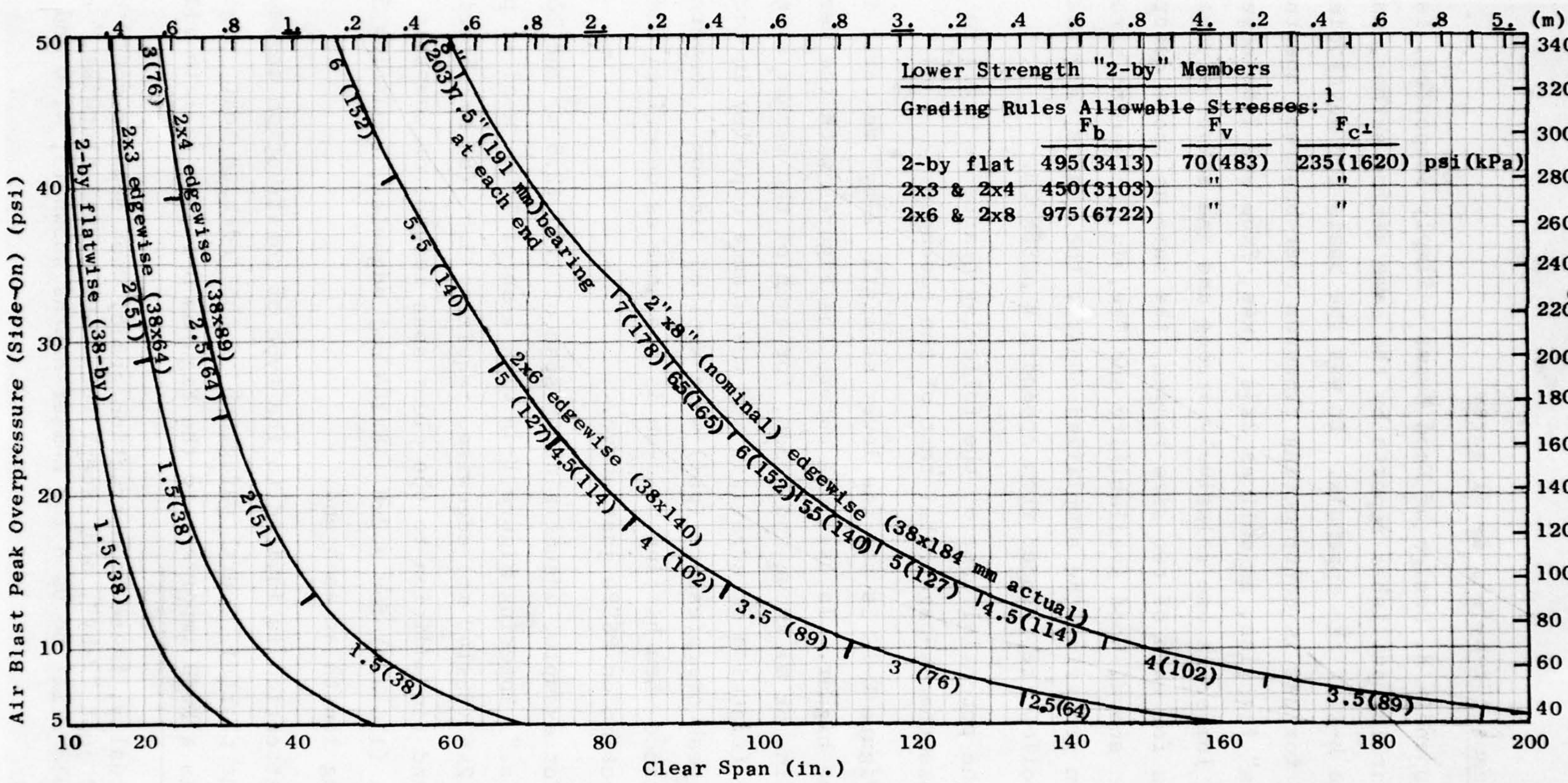

FIGURE B-1A DESIGNS OF CLOSURES USING "2-BY" MEMBERS

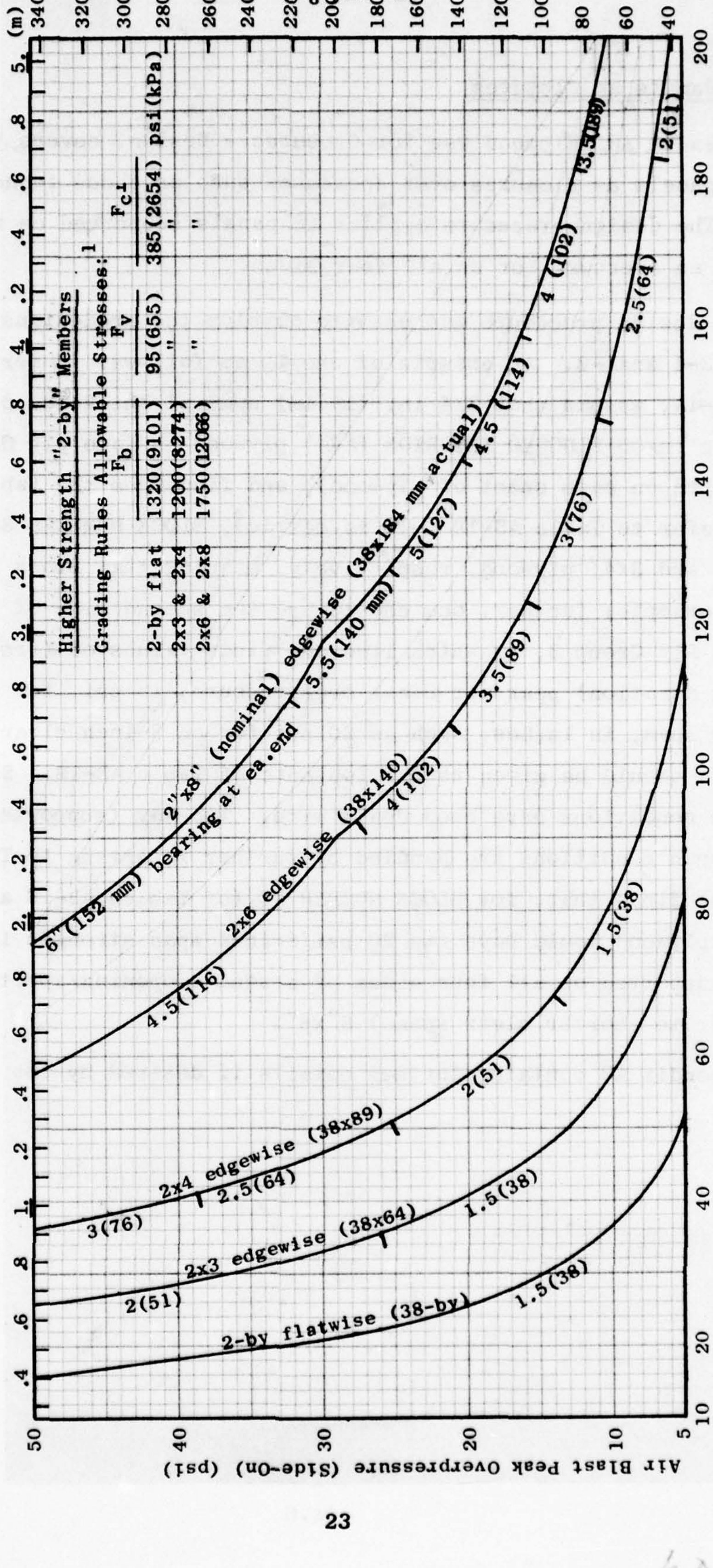

FIGURE B-1B DESIGNS OF CLOSURES USING "2-BY" MEMBERS

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Plywood Panels as Closures

Appendix A3, Plywood Use for Closures - Design, covers the design of plywood panels as closures over apertures such as those found in basements. The design procedure applies to panels supported on two opposite sides of an aperture, or on all four sides.

The design procedure was used to develop the predesigns shown by Tables A3-1 and -2. An example of use is as follows: Referring to Table A3-1A, assume that 3/4 in. (19 mm) nominal thickness plywood is available in CD-PLUGGED INTERIOR (APA) plywood in face ply GROUP 3 (so stamped on each sheet of plywood), and find from the table that one should refer to Table A3-1B (-1C is metric), BLOCK NUMBERS 8 and 16, for 1/2" and 3/4" plywood, respectively, meaning that Block No. 16 applies to this example; further, one should use the second line of that Block for Face Ply Group 3, in which line one finds values of (free field, side-on, long duration) peak air blast overpressure, in psi, for seven values of clear span, in inches, such as 20 psi for an 8-inch clear span. Attention should be given to the footnote of Table A3-1B. So far one-way span conditions have been dealt with. Two-way (supported on all four sides) span conditions are handled by further referring to Table A3-2 where one finds that, for BLOCK NUMBER 16 (of Tables A3-1B and C), the assumed plywood would have its 20 psi/8-inch span strength increased by 19% if supported on all four sides of a square opening/aperture (1:1 ratio of longer to shorter clear spans) 8"x8".

Appendix A3 contains further details if desired by the user.

Table A3-1A PLYWOOD PANELS AS CLOSURES (ONE-WAY)

Plywood panels considered herein are each stamped with American Plywood Association (APA) Type (Interior or Exterior), Grade and, in most cases, with Face Ply Species Group(s) (the latter exception is discussed further below), as follows:

Plywood Type and Grade	Table A3-1B&C Block Nos.
C-D INTERIOR (APA),* usual:	3,11
If "interior with exterior glue" is specified:	2,10
UNDERLAYMENT INTERIOR (APA), usual:	8,16
If "interior with exterior glue" is specified:	7,15
C-D PLUGGED INTERIOR (APA), usual:	8,16
If "interior with exterior glue" is specified:	7,15
2.4.1 INTERIOR (APA), usual:	18
If "interior with exterior glue" is specified:	17
APPEARANCE GRADES (Interior) (APA),† usual:	6,14
If "interior with exterior glue" is specified:	5,13
C-C EXTERIOR (APA)*	1,9
UNDERLAYMENT EXTERIOR (APA)	7,15
C-C PLUGGED EXTERIOR (APA)	7,15
APPEARANCE GRADES (Exterior) (APA),‡ with Surface A or C, face & back:	4,12
With Surface B face or back:	5,13

* Face Ply Species Groups are as follows: When stamped 24/0 on 1/2 in. (13 mm) thick plywood, Group 4; 32/16, Group 1; on 3/4 in. (19 mm): 42/20, Group 3; 48/24, Group 1.

† Generally applied where a high quality surface is required; includes N-N, N-A, N-B, N-D, A-A, A-B, A-D, B-B and B-D INTERIOR (APA) Grades.

‡ Generally applied where a high quality surface is required; includes A-A, A-B, A-C, B-B, B-C, HDO and MDO EXTERIOR (APA) Grades.

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Table A3-1B PLYWOOD PANELS AS CLOSURES (ONE-WAY)*

Block No.	PLYWOOD Nom. Th. in.	Surface Finish	Grade Str. Level	Face Ply Grp	(SIDE-ON) PEAK AIR BLAST OVERPRESSURE VS. CL. SPAN — Clear Span, in. 4	6	8	10	12	14	16	18	20	22	24	26	28
1.	1/2	UNSANDED	S-1	1	31	21	15	11	8	6	psi						
				2,3	31	21	12	8	5								
				4	31	20	11	7	5								
2.	1/2	UNSANDED	S-2	1	31	21	14	9	6	5							
				2,3	31	18	10	7	5								
				4	31	17	10	6									
3.	1/2	UNSANDED	S-3	1	28	19	14	9	6	5							
				2,3	28	18	10	7	5								
				4	28	17	10	6									
4.	1/2	SANDED	S-1	1	36	24	18	12	8	6	5						
				2,3	36	23	13	8	6								
				4	36	22	12	8	5								
5.	1/2	SANDED	S-2	1	36	24	15	10	7	5							
				2,3	36	20	11	7	5								
				4	36	18	10	7	5								
6.	1/2	SANDED	S-3	1	32	21	15	10	7	5							
				2,3	32	20	11	7	5								
				4	32	18	10	7	5								
7.	1/2	TOUCH-S.	S-2	1	31	21	16	10	7	5							
				2,3	31	20	11	7	5								
				4	31	19	10	7	5								
8.	1/2	TOUCH-S.	S-3	1	28	19	14	10	7	5							
				2,3	28	19	11	7	5								
				4	28	19	10	7	5								
9.	3/4	UNSANDED	S-1	1	50	33	25	20	15	11	9	7	6	5			
				2,3	50	33	24	16	11	8	6	5					
				4	50	33	23	15	10	8	6	5					
10.	3/4	UNSANDED	S-2	1	50	33	25	18	13	9	7	6	5				
				2,3	50	33	21	13	9	7	5						
				4	50	33	19	12	9	6	5						
11.	3/4	UNSANDED	S-3	1	45	30	23	18	13	9	7	6	5				
				2,3	45	30	21	13	9	7	5						
				4	45	30	19	12	9	6	5						
12.	3/4	SANDED	S-1	1	58	39	29	20	14	10	8	6	5				
				2,3	58	39	22	14	10	7	5						
				4	58	37	21	13	9	7	5						
13.	3/4	SANDED	S-2	1	58	39	26	17	12	8	6	5					
				2,3	58	33	19	12	8	6	5						
				4	58	31	17	11	8	6							
14.	3/4	SANDED	S-3	1	53	35	26	17	12	8	6	5					
				2,3	53	33	19	12	8	6	5						
				4	53	31	17	11	8	6							
15.	3/4	TOUCH-S.	S-2	1	51	34	25	17	12	9	7	5					
				2,3	51	34	20	13	9	6	5						
				4	51	33	18	12	8	6	5						
16.	3/4	TOUCH-S.	S-3	1	46	31	23	17	12	9	7	5					
				2,3	46	31	20	13	9	6	5						
				4	46	31	18	12	8	6	5						
17.	1-1/8	TOUCH-S.	S-2	1-3		52	39	31	25	19	14	11	9	8	6	5	5
18.	1-1/8	TOUCH-S.	S-3	1-3		51	38	30	25	19	14	11	9	8	6	5	5

* Face ply grain running in span direction (i.e., perpendicular to the two supports). Required bearing length at each end (beyond clear span) is 1½ in. (38 mm) in all cases.

Table A3-1C PLYWOOD PANELS AS CLOSURES (ONE-WAY)*

	PLYWOOD				(SIDE-ON) PEAK AIR BLAST OVERPRESSURE VS. CLEAR SPAN											
					Clear Span, mm											
Block No.	Th. mm	Surface Finish	Grade Str. Level	Face Ply Grp	100	150	200	250	300	350	400	450	500	550	600	650
1.	13	UNSANDED	S-1	1	216	144	108	78	54	40	kPa					
				2,3	216	144	85	55	38							
				4	216	144	81	52	36							
2.	13	UNSANDED	S-2	1	216	144	101	64	45							
				2,3	216	130	73	47								
				4	216	120	68	43								
3.	13	UNSANDED	S-3	1	196	130	98	64	45							
				2,3	196	130	73	47								
				4	196	120	68	43								
4.	13	SANDED	S-1	1	249	166	125	84	58	43						
				2,3	249	164	92	59	41							
				4	249	155	87	56	39							
5.	13	SANDED	S-2	1	249	166	108	69	48	35						
				2,3	249	140	79	50	35							
				4	249	130	73	47								
6.	13	SANDED	S-3	1	226	151	108	69	48	35						
				2,3	226	140	79	50	35							
				4	226	130	73	47								
7.	13	TOUCH-S.	S-2	1	219	146	110	71	49	36						
				2,3	219	143	80	51	36							
				4	219	132	74	48								
8.	13	TOUCH-S.	S-3	1	199	132	99	71	49	36						
				2,3	199	132	80	51	36							
				4	199	132	74	48								
9.	19	UNSANDED	S-1	1	352	235	176	141	110	81	62	49	40			
				2,3	352	235	173	111	77	57	43	34				
				4	352	235	165	105	73	54	41					
10.	19	UNSANDED	S-2	1	352	235	176	131	91	67	51	40				
				2,3	352	235	149	95	66	49	37					
				4	352	235	137	88	61	45	34					
11.	19	UNSANDED	S-3	1	319	212	159	127	91	67	51	40				
				2,3	319	212	149	95	66	49	37					
				4	319	212	137	88	61	45	34					
12.	19	SANDED	S-1	1	406	271	203	143	99	73	56	44	36			
				2,3	406	271	156	100	70	51	39					
				4	406	264	149	95	66	49	37					
13.	19	SANDED	S-2	1	406	271	184	118	82	60	46	36				
				2,3	406	238	134	86	60	44	34					
				4	406	220	124	79	55	40						
14.	19	SANDED	S-3	1	368	245	184	118	82	60	46	36				
				2,3	368	238	134	86	60	44	34					
				4	368	220	124	79	55	40						
15.	19	TOUCH-S.	S-2	1	357	238	178	124	86	64	49	38				
				2,3	357	238	141	91	63	46	35					
				4	357	233	131	84	58	43						
16.	19	TOUCH-S.	S-3	1	323	215	162	124	86	64	49	38				
				2,3	323	215	141	91	63	46	35					
				4	323	215	131	84	58	43						
17.	29	TOUCH-S.	S-2	1-3		361	271	216	180	132	101	80	65	54	45	38
18.	29	TOUCH-S.	S-3	1-3		354	266	213	177	132	101	80	65	54	45	38

* Face ply grain running in span direction (i.e., perpendicular to the two supports). Required bearing length at each end (beyond clear span) is $1\frac{1}{2}$ in. (38 mm) in all cases.

Table A3-2 PLYWOOD PANELS AS CLOSURES (TWO-WAY)

The purpose of this Table is to provide conversion percentages (increases) so that the user can use the data of Tables A3-1B and C to obtain overpressure versus clear span data for two-way plywood panels (that is, supported on all four sides of the opening/aperture to be closed).

This Table is based on using plywood panels with their face ply grain running in the direction of the shorter of the aperture's two clear spans. Its results are expressed in terms of the ratio of the longer to the shorter of the two clear spans; such results are expressed as percentage increases in overpressure resistance values applied to the values in Tables A3-1B and C, with such increases related to the BLOCK NUMBERS of those tables.

Recommended support bearing length on all four sides is 1½ in. (38 mm.).

TABLES A3-1B&C	RATIO OF LONGER TO SHORTER CLEAR SPANS			
BLOCK NUMBERS	1:1	1.25:1	1.5:1	2:1
1 - 3	6%	2%	1%	*
4 - 6	23	10	5	1%
7, 8	7	3	1	*
9 - 11	15	6	3	1
12 - 14	47	19	9	3
15, 16	19	8	4	1
17, 18	43	18	9	3

* Less than 1/2%

Plywood Stressed-Skin Panels (Two-Sided) as Beam-Columns

Appendix A2 deals with this subject, with the design procedure aspect completed. Further work could not be done because of project funds limitations, but the work is planned for use in the next phase of this overall research work. In contrast to the additional work on the immediately preceding section, however, PSSPs as column supports, such as intermediate supports for first floor slab beams/girders, will require discussion of where and how much support is needed and how such things may be determined on both short and not-so-short warning periods.

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Literature Search

A search through the Government Reports Index (GRI) was made for the period Sept 1975 - Sept 1976.* Selected key words used were: blast; buildings; civil defense systems; construction; fallout shelters; nuclear explosion damage; nuclear explosions, underground structures; shelters; and structures.

A search of Nuclear Science Abstracts (NSA) was also conducted for Sept 1975 - June 1976* using both index (selected key words were: civil defense; shelter; and, structures) and table of contents (protective structures and equipment and civil defense headings). (After June 1976, NSA was replaced by a new international publication Atomindex which contained no pertinent headings in the table of contents, and a search through the subject index revealed no references under the selected key words.)

A search was made of Applied Science and Technology Index (AS&TI) for 1975 - Sept 1976.* Selected key words were: air raid shelter; atomic bomb shelter; atomic bombs and building; bracing; building; civilian defense; shelter; shoring and underpinning; structural engineering - design; and, underground structures.

Finally a search of the American Society of Civil Engineers (ASCE) Index was conducted for September 1975 - August 1976* using these selected key words: building; construction; structural engineering; and, subsurface structures.

From the searches, some 10 references were selected (3 from GRI; 4 from NSA; 2 from AS&TI; and 1 from ASCE Index) for review by the Project Leader. None was useful for the predesigns herein; they were noted for review during the next phase of the continuing work.

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* A search through prior years was made for the first-phase work.[1(App.A)]

Further Work

Further work is needed in this research area, most especially in this wood use area and on tests to determine resistance behavior through the full range of loadings to collapse - of PSSPs, plywood panels and wood beams. Close collaboration between an analytical research project, such as this one, and a tests project would greatly strengthen the work of both.

There are Further Work sections in each of Appendices A1, A2 and A3 - the last section in each case - to supplement the comments above.

Acknowledgments

Through suggestions and guidance, the technical help of G. N. Sisson and M. A. Pachuta, U.S. Defense Civil Preparedness Agency, was freely given and is gratefully acknowledged; similarly acknowledged is the work of a colleague, E. E. Pickering, Sr. Civil Engineer, in contributing the Introduction section and Appendix C, and the considerable assistance readily given by the staff and Head (the late J. M. "Mike" Carney, P.E., and his successor, Wm. A. Baker, P.E.), Engineering Service, Applied Research Department, American Plywood Association, Tacoma, Washington 98401.

Note

Every effort has been made to ensure the accuracy of all guidance and programs included herein. However, no warranty, expressed or implied, is made as to the recommended procedures or programs. The reader-user is expected to make the final evaluation as to the usefulness of all material contained herein. Recommendations made herein should not be substituted for the knowledge, experience, and judgment of the professional engineer or architect, but should be treated as guidance for consideration by the professional, regarding the best method of achieving specific design goals.

REFERENCES

1. Murphy, H. L., C. K. Wiehle, and E. E. Pickering, Upgrading Basements for Combined Nuclear Weapons Effects: Expedient Options, Stanford Research Institute* Technical Report, for Defense Civil Preparedness Agency, May 1976. (AD-A030 762)†

2. Murphy, H. L., J. R. Rempel, and J. E. Beck, SLANTING IN NEW BASEMENTS FOR COMBINED NUCLEAR WEAPONS EFFECTS: A Consolidated Printing of Four Technical Reports, Stanford Research Institute Technical Reports, 3 vols., for U.S. Defense Civil Preparedness Agency, October 1975. (AD-A023 237)

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4. National Design Specification for Stress-Grade Lumber and Its Fastenings, National Forest Products Association, 1619 Massachusetts Avenue, N.W., Washington, D.C. 20036, 1973 edition, with Table 1 Supplement (allowable unit stresses, published separately), April 1973, revised November 1974.

5. Plywood Design Specification (PDS), American Plywood Association, 1119 A Street, Tacoma, Washington 98401, revised December 1976.

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* Now SRI International (Menlo Park, California 94025).

† References for which "AD-" numbers are shown are understood to be available for purchase from NTIS, Springfield, Virginia 22151.

Appendix A

PLYWOOD APPLICATIONS

Precedeing Page BLank - NOT FILMED

Appendix A1

PLYWOOD STRESSED-SKIN PANELS (TWO-SIDED ONLY) AS CLOSURES - DESIGN AND FABRICATION

Preceding Page Blank - NOT FILMED

CONTENTS

TABLES

FIGURES

Preceding Page Blank - Not Filmed

Design

A design procedure for plywood stressed-skin panels was developed because plywood and suitable wood members for the necessary stringers are in abundant supply in local lumberyards, and because efficient use of such materials can assist greatly in meeting the existing basement upgrading need for many closures against air blast entry into the basement.

Existing design procedures were studied, used as a basis for developing the procedure that follows, but had to be carefully reviewed/modified/rederived to make them both dimensionally consistent (and thus more readily convertible to metric units, a contract requirement) and usable for panel widths other than 48 in. (a limitation built into the present procedure).[1,2*]

The developed design procedure is limited to plywood stressed-skin panels with both top and bottom skins, both of which are used with the grain of the outer plies parallel to the stringers. Adequate shear transfer between plywood (flanges) and stringers (webs) is assumed, based on using pressure-glued or nail-glued joining techniques. The normal-use allowable stresses in the procedure are intended for application to panels at least 2 ft wide (measured perpendicular to stringers); narrower panels are subject to reductions in allowable stresses.[2(p.19)]

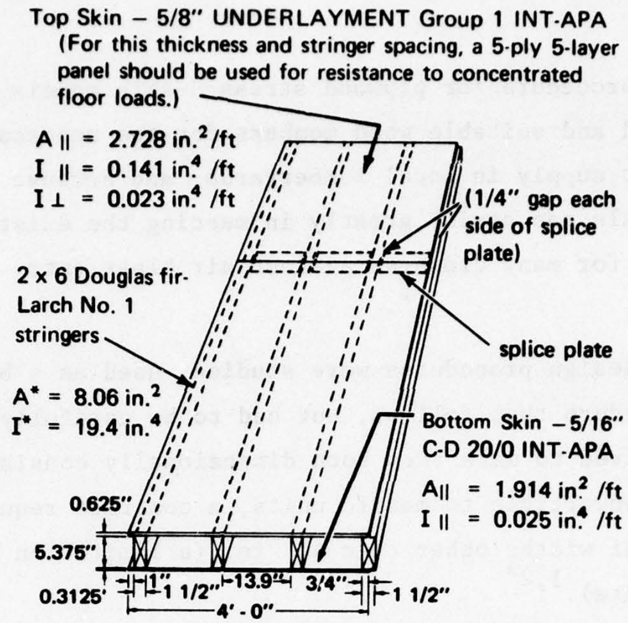
Design Procedure. The design procedure (steps) follows:

1. Assume a trial section and clear span (in direction of stringers), and that panel is fully and uniformly loaded. See Figure 1A.

2. Get values for b ("b distance"), both for top b_t and bottom b_b skins (Figure 1B). If clear distance between stringers, Figure 1A, exceeds 2b for both skins, this design procedure is inapplicable.[1(p.5)]

3. Calculate N.A. (neutral axis location) for deflection. Use bottom of panel as reference line for moment arms y applied to areas $A_{//}E$,

* Reference 2 must be held by the user, particularly for its Tables, pp. 9, 14-17 and 26; holding Reference 1 is unnecessary but may be desirable.



$$\text{Clear distance between stringers} = \frac{48 - 3\times1.5 - 1 - 0.75}{3} = 13.9''$$

$$\text{Total splice plate width} = 3(13.9 - 0.5) = 40.2''$$

*Includes a 1/8" reduction in depth to allow for resurfacing.

A.

Basic Spacing, *b*, For Various Plywood Thicknesses
(Face grain parallel to stringers*)

Plywood	Basic Spacing, *b*, (inches) Number of plies				
	3	4 (3 layer)	5 (5 layer)	6 (5 layer)	7 (7 layer)
1/4" Sanded	10				
5/16" Unsanded	12				
3/8" Unsanded	16				
3/8" Sanded	19				
1/2" Unsanded, sanded, touch-sanded	22	22	23		
5/8" Unsanded, sanded	27	35	33		
5/8", 19/32" Touch-sanded		27	32		
3/4" Unsanded, sanded, touch-sanded		36	38	38	
23/32" Touch-sanded		35	34	37	
7/8" Unsanded			48		39
7/8" Sanded					51
1" Unsanded, sanded					53
2-4-1					56

*Where plywood face grain is across stringers, write APA for appropriate "*b*" distances.

B.

FIGURE 1 PLYWOOD STRESSED-SKIN PANEL (Example Trial Section) [1(p.4)] AND TABLE ON STRINGER SPACING [1(p.5)]

counting only plies parallel to stringers (for $A_{//}$) and increasing E values (to correct from effective E to true E in bending), by 10% for skins[2(p.17),1(p.7)] and 3% for stringers.[3,1(p.7)] $A_{//}$ values are available from tables[2(p.16: note units, col. 4: in.²/ft)]. A calculation example is shown in Figure 2A.

4. Calculate panel (EI_g) using N.A. of Step 3. This stiffness factor is for moment deflection only (i.e., excludes shear deflection). Obtain I_o values for skins.[2(p.16,col.5)] Calculate I_o values for (combined) stringers ($bd^3/12$), including a portion of any stringer that is partially outside the plywood skins, as one stringer is in the calculation example shown in Figure 2B. Same E values and percentage increases are used as in Step 3.

5. Calculate allowable load (TL) - deflection:*†

$$p_d = 1 \;/\; [C\ell\ell' \left(\frac{5}{384} \frac{\ell^2}{(EI_g)} + \frac{0.15}{AG} \right)] \quad + DL$$

where: p_d = allowable TL - panel deflection (psi)

C = factor for max. allowable deflection*
(often 360 floors, 240 roofs, LL only)

(EI_g) from Step 4 (lb-in.^{2})

A = (actual) total X-sec. area of all stringers (in.^{2})

G = modulus of rigidity of stringers (psi)
(taken as 0.06 E plus 3%)

ℓ = clear span of panel (in direction of stringers)(in.)

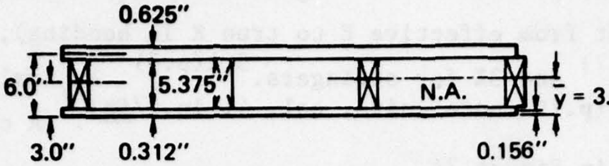
ℓ' = width of panel (skins only)(perpendicular to ℓ)(in.)

6. Calculate allowable load (TL) - top skin deflection (cross-panel). Usually only the top skin deflection need be checked, but unusual assumed sections may require top skin moment and shear investigations.[1(p.9)] Check strip <u>1 in.</u> wide for allowable total load (TL) and deflection

---

* If C is based on TL, then p_d will be directly in TL units (psi), without adding the DL term in the equation.[1(p.9)]

† While (EI_g) excludes shear deflection, the formula for p_d includes it.

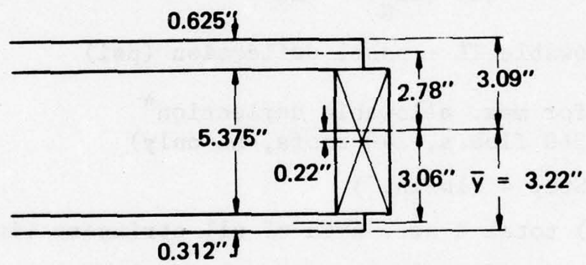


Values of $A_{\parallel}$ of plywood from PDS Table 1.

Item	E	$A_{\parallel}$	$A_{\parallel}E$	y	$A_{\parallel}Ey$
Top Skin	1,800,000 x 1.1 = 1,980,000	4 x 2.728 = 10.9	21,600,000	6.000	129,600,000
Stringers	1,800,000 x 1.03 = 1,850,000	4 x 8.06 = 32.2	59,600,000	3.000	178,800,000
Bottom Skin	1,800,000 x 1.1 = 1,980,000	4 x 1.914 = 7.66	15,200,000	0.156	2,370,000
Total		50.8	96,400,000		310,770,000

$$\bar{y} = \frac{\Sigma A_{\parallel}Ey}{\Sigma A_{\parallel}E} = \frac{310,770,000}{96,400,000} = 3.22''$$

A.



Values of I_o of plywood from PDS Table 1.

Item	E	I_o	$A_{\parallel}$	d	d^2	$A_{\parallel}d^2$	$I_o + A_{\parallel}d^2$	$E(I_o + A_{\parallel}d^2)$
Top Skin	1,980,000	0.564	10.9	2.78	7.73	84.3	84.9	168,000,000
Stringers	1,850,000	77.6	32.2	0.22	.048	1.55	79.2	147,000,000
Bottom Skin	1,980,000	.100	7.66	3.06	9.36	71.7	71.8	142,000,000
Total							I_g = 235.9	457,000,000

$$EI_g = 457,000,000 \text{ lb-in.}^2 \text{ per 4-ft width}$$

B.

FIGURE 2 NEUTRAL AXIS FOR DEFLECTION AND $(EI_g)_{I(p.8)}$
(Calculations Examples)

(FF or fixed ends beam assumption), based on cross-panel top skin deflection behavior, as follows:

$$p_t = 384\ EI\ /\ [C(\ell'')^3] + DL$$

where: p_t = allowable TL - top skin deflection (psi)

C = factor for max. allowable deflection*
(often 360 floors, 240 roofs, LL only)

E is for top skin[2(p.17, no 10% added)] (psi)

I is for stress applied perpendicular to stringers and face grain[2(p.16,col.9)]; table's in.^{4}/ft values must be changed to in.^{4}/in.

ℓ'' = clear distance between stringers (Step 2 and Fig 1A) (should be uniform; if not, use longest value)(in.)

Mid-span cross-panel deflection, of course, then equals ℓ''/C.

7. Calculate N.A. for bending. Effective width of skins (as "flanges" to each stringer) is b/2 on each side of stringer, plus the width of the stringer. Get b from Step 2. Make sketch showing effective widths with each stringer, of both top and bottom skins. Calculate N.A. location, using bottom of panel as reference line for moment arms y; see example, Figure 3A; E values are used plus percentages, as in Step 3. Recall that $A_{//}$ tabular values are in in.^{2}/ft width and must be corrected for effective width of skins (versus total width used in Step 3), as must I_o skin values; moment arms for skins and stringers are the same as in Step 3. NOTE: Non-Stress-Graded stringers are omitted in the calculations of this Step (i.e., valued at zero), even though in Steps 3 and 4 they would be included.

8. Calculate (EI_n) for bending. Use all data from Step 7, plus using I_o for each skin as flanges (from Step 4, but correcting I_o values from full panel width to "effective widths" of Step 7), again correcting for tabular units of in.^{4}/ft width, as necessary; use I_o values for stringers, as in Step 4 (omit Non-Stress-Graded stringers, though, as in Step 7). See example calculations, Figure 3B.

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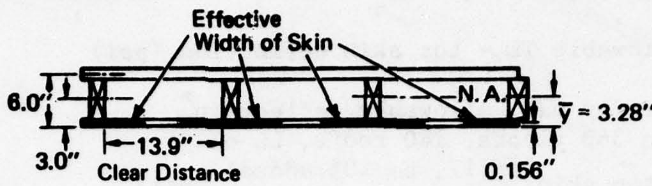
* If C is based on TL, then p_t will be directly in TL units (psi) without adding the DL term in the equation.[1(p.9)]

Effective width of top skin = 48"

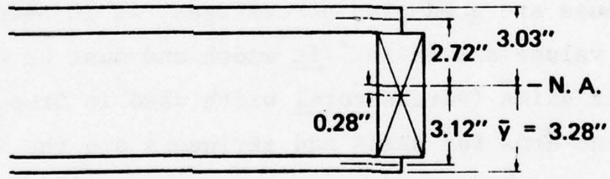
Effective width of bottom skin = 48" -3(13.9 – 12) = 42.3"



Item	E	A‖	A‖E	y	A‖Ey
Top Skin	1,980,000	10.9	21,600,000	6.00	129,600,000
Stringers	1,850,000	32.2	59,600,000	3.00	178,800,000
Bottom Skin	1,980,000	$\frac{42.3}{12} \times 1.914 = 6.75$	13,400,000	0.156	2,090,000
			94,600,000		310,490,000

$$\bar{y} = \frac{\Sigma A \parallel Ey}{\Sigma A \parallel E} = \frac{310,490,000}{94,600,000} = 3.28''$$

A.



Item	E	I_o	A‖	d	d^2	A‖d^2	I_o + A‖d^2	E(I_o + A‖d^2)
Top Skin	1,980,000	0.584	10.9	2.72	7.40	80.7	81.3	161,000,000
Stringers	1,850,000	77.6	32.2	0.28	0.078	2.51	80.1	148,000,000
Bottom Skin	1,980,000	0.068	6.75	3.12	9.73	65.7	65.8	130,000,000
							I_n = 227.2	439,000,000

$$EI_n = 439,000,000 \text{ lb-in.}^2 \text{ per 4-ft width}$$

B.

FIGURE 3 NEUTRAL AXIS FOR BENDING MOMENT AND (EI_n)
(Calculations Examples)[1(p.10,11)]

9. Determine top skin allowable compressive stress. Obtain F_c.[2(p.17)] Correct F_c by using ratio of clear distance between stringers ℓ'' (Step 6) to b_t (Step 2), as follows: for ratio ≤ 0.5, use 100%; for ratio ≥ 1.0 up to 2.0 (see parenthetic comment in Step 2), use 67%; and for ratios between 0.5 and 1.0, vary percentage correction linearly between 100% and 67%.[1(p.11)*]

10. Determine bottom skin allowable tensile stress. Obtain F_t.[2(p.17)] Correct F_t in same manner as Step 9 (for F_c), using b_b from Step 2.[1(p.11)]

11. Calculate allowable load (TL) - bending:

$$p_b = (8\ F\ /\ (c\ell'\ell^2))\ ((EI_n)\ /\ E)$$

where: p_b = allowable load (TL) - bending (psi)

$F = F_c$ or F_t from Steps 9 and 10, as appropriate (psi)

(EI_n) from Step 8 (lb-in.^{2})

E for skin under check, top or bottom (as in Step 3, including percentage increase)(psi)

c = distance from N.A. for <u>bending</u> (Step 7) to extreme fibre (of skin under check, top or bottom)(in.)

ℓ and ℓ' are same as in Step 5 (in.)

Check p_b for both top (p_{bt}) and bottom (p_{bb}) skins, then use smaller value as the applicable p_b.

12. Calculate allowable load (TL) - rolling shear:

It is generally sufficient to check rolling shear only in the thicker skin (it usually has the larger Q_s of the two skins, which leads to a smaller allowable load).[1(p.13)] The skin's <u>critical plane</u> for checking (in panels with face plies parallel to stringers, a fundamental limitation in the overall procedure herein) is along the glued plane on the inner side of the inside face ply of the panel; see Figure 4A.

Find area A (in.^{2}) for parallel-grain plies outside the critical plane (note that tabular values are for 48-in. wide panels, so must be corrected proportionately for other panel widths ℓ'), Figure 4B, 2nd or

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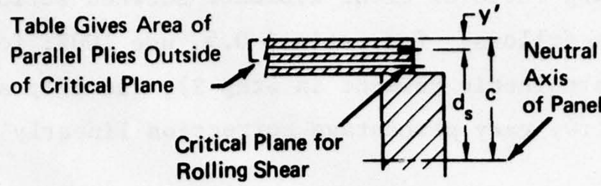
* Reference 1, p.11, figure erroneously shows 67.5% instead of correct value of 66.7% (as shown in text example and in other sources).



A.

A and y' for Computing Q_s *

Plywood Thickness (in.)	STRUCTURAL I Grades, or any Group 4 Panel				All Other Panels			
	Face Grain ∥ to Stringers		Face Grain ⊥ to Stringers		Face Grain ∥ to Stringers		Face Grain ⊥ to Stringers	
	Area (in.^{2})	y' (in.)	Area (in.^{2})	y' (in.)	Area (in.^{2})	y' (in.)	Area (in.^{2})	y' (in.)
Unsanded Panels								
5/16	4.75	0.0495	4.75	0.149	3.83	0.0479	2.64	0.149
3/8	4.45	0.0464	5.75	0.180	3.73	0.0467	3.19	0.180
1/2	5.81	0.0606	7.75	0.242	6.25	0.131	4.31	0.242
5/8	9.24	0.176	9.75	0.305	7.18	0.140	5.42	0.305
3/4	7.34	0.0765	11.8	0.367	8.16	0.208	6.53	0.367
Sanded Panels								
1/4	3.36	0.0350	4.91	0.121	3.36	0.0350	2.73	0.121
3/8	3.36	0.0350	8.51	0.184	3.36	0.0350	4.73	0.184
1/2	3.89	0.0406	9.23	0.246	3.89	0.0406	5.13	0.246
5/8	4.56	0.0475	11.7	0.309	4.56	0.0475	6.51	0.309
3/4	12.0	0.277	15.1	0.371	8.18	0.233	8.42	0.371
Touch-Sanded Panels								
1/2	4.56	0.0475	8.35	0.224	4.56	0.0475	4.64	0.224
19/32	7.93	0.174	11.6	0.276	5.90	0.139	6.44	0.276
5/8	8.21	0.185	12.3	0.288	6.06	0.148	6.86	0.288
23/32	6.06	0.0632	14.5	0.344	8.14	0.213	8.06	0.344
3/4	6.06	0.0632	15.3	0.356	8.37	0.225	8.50	0.356
2-4-1	–	–	–	–	12.7	0.359	16.5	0.547

*Area based on 48"-wide panel. For other widths, use a proportionate area.

B.

FIGURE 4 ROLLING SHEAR CRITICAL PLANE AND Q_s 1(p.14)

6th column. Calculate distance d_s (in.) from N.A. (for <u>deflection</u>, Step 3) to centroid of A, using moment arm $d_s = c - y'$ (all in. units), where c is distance from N.A. to extreme fibre and y' can be taken from table, Figure 4B. Then calculate the statical moment Q_s (in.^{3}):

$$Q_s = A\ d_s$$

Calculate $\Sigma\ F_s t$ (psi-in., or lb/in.), the sum of the glueline widths over each stringer, each multiplied by its applicable allowable rolling shear stress F_s (Reference 2, page 17) but with a 50% reduction applied to outer stringer(s) whose clear distance to a panel edge is less than half the clear distance between stringers.[1(p.15)]

Calculate allowable load (TL) - rolling shear (p_s, psi):

$$p_s = (2(\Sigma F_s t)\ /\ (\ell\ell' Q_s))\ ((EI_g)\ /\ E)$$

where: $(\Sigma F_s t)$(lb./in.), ℓ and ℓ'(in.), and Q_s(in.^{3}) are defined above

(EI_g) from Step 4 (lb-in.^{2})

E for skin under check, usually thicker one (tabular value plus 10% if taken from Ref. 2, p. 17)

13. Calculate allowable load (TL) - horizontal shear:

Calculate statical moment Q_v of all parallel-grain plies and stringers in full panel width ℓ', working <u>either</u> above <u>or</u> below* the N.A. for deflection (Step 3 and Figure 2 can provide numerical data for these $Q_v = A\ d$ calculations, as an example of course):

$$Q_v = Q_{stringers} + Q_{skin}\ [\ E_{skin}\ /\ E_{stringers}\ ]$$

where: Q_v is defined above (in.^{3})

$Q_{stringers}$ = x-sec. area of all stringer portions <u>either</u> above <u>or</u> below N.A. (depending on chosen approach)* times its centroidal distance from deflection N.A. (as moment arm) (in.^{3})

$Q_{skin} = A_{//}$ for chosen skin × moment arm (in.^{3})[2(p.16, col. 4 for $A_{//}$)]

E's as before (Step 3, including percentage increases)(psi)

---

* Calculations "below" are easier, if deflection N.A. calculations (Step 3) were made as stated, i.e., using bottom surface of panel as reference plane.

Calculate:

$$p_v = (2\ F_v t\ /\ (\ell\ell' Q_v))\quad ((EI_g)\ /\ E_{st})$$

where: p_v = allowable load (TL) - horizontal shear (psi)

F_v = allowable stress in stringer horizontal shear (psi)[3(Table 1)]

t = sum of stringer widths (including side projecting portions, Figures 1A and 2)(in.)

(EI_g) from Step 4 (lb-in.^{2})

E_{st} for stringers, as in Step 3 including percentage increase (psi)

ℓ, ℓ', and Q_v as above (in., in., and in.^{3})

14. Calculate required end bearing length:

The preceding steps that have led to allowable load (TL) under various criteria have used ℓ = clear span (in.)(Steps 5,6,11,12 and 13), but for end bearing, the full length of the panel will be greater than ℓ, sufficiently to provide for the allowable load (TL) in end bearing. Further, properly installed headers will have to be capable of spreading the end bearing load across the full panel width of the (thin) bottom skin; *thus continuous headers crossing* (nail-glued or pressure-glued) the stringer ends, and within the cover of both top and bottom skins, are recommended (see Reference 1, page facing page 1, top sketch, <u>far</u> end, for example).

The following approach to calculating ℓ_e (required plywood end bearing length at <u>each</u> end) considers adoption of the continuous-headers recommendation just above, but may be also used, perhaps with less confidence in ultimate strength behavior, for blocking-type headers (see same Reference 1 sketch, <u>near</u> end, for an example).

Let: ℓ_e = required plywood end bearing length at <u>each</u> end of panel (in.)

ℓ = clear span of panel, as before (in.)

ℓ' = full panel width (skins only)(note: entire panel area, including end bearing lengths, are assumed to be under a uniform loading)(in.)

p_m = smallest of the calculated allowable loads (TL), from Steps 5, 6, 11, 12 and 13 (psi)

$F_{c\perp}$ = allowable bearing stress on plywood face, for load perpendicular to plane of outer ply actually in bearing (psi)[2(p.17)]

Then: applied load must be less than or equal to resisting capacity:

$$p_m \ell \ell' \leq 2\, \ell' \ell_e F_{c\perp}$$

or ℓ_e (min. at each end of panel) $= p_m \ell \,/\, (2\, F_{c\perp})$

It is recommended that ℓ_e be at least 1.5 in. (38 mm).

The bearing length of each stringer end (at least 1.5 or 2 inches) (38 or 51 mm) should be sufficient to handle the unit blast load on the plywood panel multiplied by the maximum c-c spacing of stringers and divided by the stringer width, all in accordance with Appendix B (especially Figure 6-12, which may be extended as needed based on last "bullet" paragraphs on page 6-111). See also Figures 9 later herein.

15. Glued plywood end joints (across face grain):[2(p.25,Sec.5.6)]

15A. Scarf joints: Sketches of end-of-grain joints are available.[4(p.9-11)] Scarf joints are made by bevelling across the plywood end edges (i.e., perpendicular to stringers and face plies of top and bottom skins), then joining the bevelled ends with an appropriate adhesive.

For the tension skin: 1 in 8 or flatter bevels transmit 100% of full allowable stress; 1 in 5 transmit 75%; use linear proportioning between these two bevels; and steeper than 1 in 5 are not to be used.[2(p.25)]

For compression skin: 1 in 5 or flatter bevels transmit 100% of allowable stress; steeper than 1 in 5 are not to be used.[2(p.26)]

(Note: Finger joints are too complicated to form and otherwise unsuitable for further consideration herein.)

15B. Splice-plate design (butt joints): While scarf joints are the recommended technique, this design section is presented for use if needed.[1(p.12,Sec.2.5.6)]

For a splice-plate illustration, see Figure 1[(2,p.4)] or top sketch of page facing page 1 of reference 1.

Splice-plates are to: be 1/4 in. clear of stringers at both plate ends; have skin face grain perpendicular to splice; be of grade and species group equal to the plywood spliced; and be no thinner than the skin being spliced. Tension skins with splice-plates are capable of transmitting 100% of maximum allowable stress.[2(p.26,table)] If the splice-plate is shorter than required for use of an allowable stress in the referenced table, the allowable stress is to be reduced proportionately.

Calculate splice plate allowable load (TL) - tension:

$$p_p = (8\ F\ /\ (c\ell'\ell^2))\ \ ((EI_g)\ /\ E)$$

where: p_p = allowable load (TL) on tension splice at point of max. moment (psi)

F = allowable splice-plate stress × proportion of panel width actually spliced[2(p.26,table)]

c = distance from deflection neutral axis to extreme bottom (tension) fibre (in.)

c and (EI_g) are as in Figure 2A ($\bar{y}$) and Step 4, respectively (in. and lb-in.^{2})

E is for tension skin, as used in Step 3 (with the percentage increase)(psi)

ℓ and ℓ' are as before (in.)

Splice plate allowable load (TL) - compression: These plates can be approved by inspection, for 100% transmittal of allowable stress, subject to cited references.[2(Sec.5.6.1.2 and 5.6.2.2)]

Design Stresses - Blast Protection Use versus Normal Use. The design procedure detailed above is that for normal, day-to-day uses, for which allowable stresses are prescribed.[2(p.17),3] Such allowable stresses are totally inappropriate for one-time blast loadings, with their extremely short (essentially zero) rise-times and short durations (1 or 2 seconds in our range of interest, even for megaton weapons), inappropriate in that they result in seriously underestimating the ultimate strength of structural members under blast loadings. The reader is referred to Appendix B herein, especially the introductory section and the "Design Procedure" section; within the latter, specific attention is

invited to its introductory section and design steps 1 through 4. Such referenced reading covers the very basic structural dynamics, bilinear blast resistance, ductility ratio μ, etc., as well as the increased stresses used in blast-resistant design: for wood beams, the increases are four times for F_b and F_v (extreme fibre stress in bending and horizontal shear stress, respectively) and no increase in $F_{c\perp}$ (compression stress perpendicular to grain, or bearing stress). Authorities are cited.

An examination of literature helpfully furnished by the U.S. Forest Products Laboratory, Madison, Wisconsin, indicated the following: Tests on plywood stressed-skin panels (PSSPs) to destruction were few in the literature furnished, being restricted to tests on PSSPs with narrow, plywood stringers where all (predictably) failed along the stringer gluelines; the allowable stress increase of 100% for impact loads[2(Sec.3.3.1.1)] seems to be well supported by a test report[5] in terms of both short duration loads and fast rate of loading, for both wood and wood-based materials (including plywood).

If one considers that "allowable" stresses in most cases (and materials types) are based on a factor of safety of about two, we can then arrive at a factor of four (including the 100% for impact) for ultimate strength under short, rapidly applied loads - a factor of four for certain stresses, at least. These stresses might include, for PSSPs:[2(p.17)] F_b, F_t, F_c, F_v and F_s, but not $F_{c\perp}$.

Pending receipt of better information based on sorely needed tests, these dynamic stress increases were tentatively adopted for use herein; test data found were for static loadings, or for loads within severe limits on deflection, or for loadings far short of failure/collapse (as used in typical air blast loadings and design technology).[5,6]

For a value of the ductility ratio μ, however (see App. B, Design Step 3), a value of two was similarly and tentatively adopted for PSSPs, with a value of three tentatively continued for wood beams,* again hoping to obtain appropriate test information in the early future. For a

* In Appendix B following.

dynamic load simplified to a step pulse (zero rise-time to a constant loading of infinite duration), the relationship is

$$p_{dm} = p_m (1 - 1/(2\mu)) = p_m(3/4), \text{ for } \mu = 2$$

Typical Designs of PSSPs. In order to handle the many sets of design computations required in producing a reasonably adequate catalog of pre-designs, a computer program was prepared (in Dartmouth BASIC), following the above 15-step design procedure (Step 15 on design of plywood end joints was not included in the design output, although it is included in the computer program). A listing of the computer program is shown herein (Table 1).

The pre-designs* covered clear span ranges from 24" to 96" for lighter panels and from 24" to 144" for heavier. Stringers included 2x4s, 2x6s and 2x8s of both relatively low and high strengths, thereby covering a considerable range of lumber species among those readily available in local lumberyards. Several plywood types/species/grades were examined, with complete pre-designs using two types/grades throughout; this was coupled with use of face ply species groups #1 and #3, except that #3 was not used for the 1-1/8" plywood because of unavailability.† Tabulated designs also show type of failure predicted by the design procedure, based on the allowable design increases and μ value (i.e., 2) described in the preceding section; however, selection of the p_{dm} (ultimate dynamic blast strength/resistance, psi) was based on the least value from the design calculations for flexure/bending, rolling shear and horizontal shear (i.e., panel deflection, to an arbitrary limitation such as 360, and cross panel deflection between stringers, were not allowed to control selection of p_{dm}). Design results include those wherein 4, 7 and 9 stringers equally spaced in 48" width panels were used, with a few results from use of 5 stringers. The pre-designs are tabulated below (Tables 2 and 4). All assume PSSP use under dry conditions (plywood equilibrium moisture content less than 16%); blast resistance would be considerably reduced by use under wet conditions.‡

The computer programs used are listed in Table 3.

---

* All included panel dead load (DL), which was less than 0.1 psi in all cases, thus p_{dm} values are appropriate for laterally loaded panels used horizontally or vertically.

† Actually available in Groups 1-3, but see footnote * on page A1-31.

‡ See footnote ‡ page 7 (main body of report).

Table 1 PSSP DESIGN: COMPUTER PROGRAM (HLMPSP) LISTING AND SAMPLE PROBLEM*

```
LIS
HLMPSP

0100 REM    PRØGRAM FØR DESIGN ØF PLYWØØD STRESSED-SKIN PANELS
0110 REM
0120 REM    PDS = PLYWØØD DESIGN SPEC.,AMER.PLYWØØD ASSN (REV.1/76)
0130 REM    PDS3= SUPPLEMENT 3 (1974) TØ PDS
0140 REM    NDS = NATL DES. SPEC. FØR STRESS-GRADE LUMBERS AND ITS
0150 REM       FASTENINGS, TABLE 1 (SUPPLEMENT,REV.11/74)
0160 REM    WDHDBK = WØØD HANDBØØK REV.8/74,U.S.FØREST PRØDUCTS LAB
0170 REM    HLMSRI = H.L.MURPHY REPØRT DESCRIPTIØN ØF DESIGN PRØCEDURE
0180 REM
0190 DIM N[20],A$[10],B$[10]
0200 GØSUB 540
0210 GØSUB 730
0220 GØSUB 1050
0230 GØSUB 1330
0240 GØSUB 1720
0250 GØSUB 1910
0260 GØSUB 2270
0270 GØSUB 2610
0280 GØSUB 2830
0290 GØSUB 3400
0300 GØSUB 3540
0310 GØSUB 3990
0320 GØSUB 5000
0330 PRINT "ANY CHANGES DESIRED (YES ØR NØ) "
0340 INPUT B$
0350 IF B$="NØ" THEN 430
0360 PRINT "GIVE ØNE STEP NUMBER WHERE CHANGE(S) DESIRED "
0370 INPUT N2
0380 IF INT(N2)<1 THEN 360
0390 IF INT(N2)>15 THEN 360
0400 GØSUB N2 ØF 540,540,730,1050,1330,1720,1910,2270,2270,2270
0410 GØSUB N2-10 ØF 2610,2830,3400,3540,3990
0420 GØTØ 330
0430 PRINT
0440 PRINT "WANT TABULATIØN ØF INPUT VALUES (YES ØR NØ) "
0450 INPUT B$
0460 IF B$="NØ" THEN 490
0470 GØSUB 4240
0480 GØTØ 320
0490 GØSUB 5000
0500 REM ********************
0510 REM * STEP 2  (HLMSRI) *
0520 REM ********************
0530 GØTØ 640
0540 PRINT "STEP 2:"
0550 PRINT "ENTER 'B' DISTANCES FØR TØP & BØT. SKINS, RESP'Y(IN.)"
0560 PRINT "   (HLMSRI, FIG.1B; ALSØ PDS3, P.5(TABLE))"
0570 INPUT B1,B2
0580 PRINT
0590 PRINT "ENTER CLEAR DISTANCE BETWEEN STRNGRS (FIG.1A,HLMSRI)(IN.)"
0600 PRINT "   (SHØULD BE UNIFØRM; IF NØT, USE LARGEST VALUE)"
0610 INPUT L4
0620 PRINT
0630 RETURN
0640 IF L4 <= 2*B1 THEN 720
0650 IF L4 <= 2*B2 THEN 720
0660 PRINT "WARNING: PRØGRAM DESIGN PRØCEDURE NØT APPLICABLE"
0670 PRINT "   (HLMSRI, STEP 2; ALSØ PDS3,SEC.2.2.1.1,P.5)"
0680 PRINT
0690 REM ********************
0700 REM * STEP 3  (HLMSRI) *
0710 REM ********************
0720 GØTØ 930
0730 PRINT "STEP 3:"
0740 PRINT "ENTER E VALUES (PSI) FØR TØP,BØT.SKINS & STRINGERS,RESP'Y"
0750 PRINT "   (PDS,P.17 & NDS)"
0760 INPUT E1,E2,E3
0770 PRINT
0780 PRINT "ENTER A// VALUES FØR TØP,BØT.SKINS (SQ IN/FT WIDTH)"
0790 PRINT "   (PDS,P.16,CØL.4)"
0800 INPUT A1,A2
0810 PRINT
0820 PRINT "ENTER TØTAL X-SECT.AREA ØF ALL STRINGERS (SQ IN)"
0830 INPUT A3
0840 PRINT
0850 PRINT "ENTER MØMENT ARMS FØR TØP,BØT.SKINS & STRNGRS,RESP'Y(IN.)"
0860 PRINT "   (FRØM BØTTØM SURFACE ØF PANEL)"
0870 INPUT Y1,Y2,Y3
0880 PRINT
0890 PRINT "ENTER WIDTH (PLYWØØD) ØF PANEL (IN.)";
0900 INPUT L2
0910 PRINT
0920 RETURN
0930 LET N[1]=A1/12*L2+A2/12*L2+A3
0940 LET N[2]=A1/12*L2*E1*1.1+A2/12*L2*E2*1.1+A3*E3*1.03
0950 LET N[3]=A1/12*L2*E1*1.1*Y1+A2/12*L2*E2*1.1*Y2+A3*E3*1.03*Y3
0960 LET Y7=N[3]/N[2]
0970 PRINT "STEP 3:"
0980 PRINT "Y-BAR (DEFLECTIØN N.A.) = ";Y7;"   IN."
0990 PRINT "HLMSRI FIG.2A 'TØTALS': ",N[1],N[2],N[3]
1000 PRINT
1010 REM ********************
1020 REM * STEP 4  (HLMSRI) *
1030 REM ********************
1040 GØTØ 1140
1050 PRINT "STEP 4:"
1060 PRINT "ENTER I ØF TØP,BØT.SKINS ABØUT ØWN AXES(IN.4/FT WIDTH)"
1070 PRINT "   (PDS,P.16,CØL.5)"
1080 INPUT I1,I2
1090 PRINT
1100 PRINT "ENTER TØTAL WIDTH ØF STRINGERS (IN.) ";
1110 INPUT T5
1120 PRINT
1130 RETURN
1140 LET I3=T5*(A3/T5)↑3/12
1150 LET D1=Y1-Y7
1160 LET D2=Y7-Y2
1170 LET D3=ABS(Y7-Y3)
1180 LET N1=I1/12*L2+A1/12*L2*D1↑2
1190 LET N2=I2/12*L2+A2/12*L2*D2↑2
1200 LET N3=I3+A3*D3↑2
1210 LET I7=N1+N2+N3
1220 LET N4=E1*1.1*N1
1230 LET N5=E2*1.1*N2
1240 LET N6=E3*1.03*N3
1250 LET E4=N4+N5+N6
1260 PRINT "STEP 4:"
1270 PRINT "(EI-SUB G) = ";E4;"   LB-IN.2"
1280 PRINT "HLMSRI FIG.2B 'TØTALS':",I7,E4
1290 REM ********************
1300 REM * STEP 5  (HLMSRI) *
1310 REM ********************
```

* Sample problem (on last two sheets) is the one used in Reference 1.

Table 1 (continued)

```
1320 GØTØ 1380
1330 PRINT "STEP 5:"
1340 PRINT "ENTER CLEAR SPAN L ØF PANEL (IN.) ";
1350 INPUT L1
1360 PRINT
1370 GØTØ 1430
1380 IF L1-INT(L1)<.01 THEN 1410
1390 LET L1=INT(L1)+1
1400 GØTØ 1420
1410 LET L1=INT(L1)
1420 GØTØ 1530
1430 PRINT "ENTER C FACTØR, IN MAX.ALLØWABLE DEFL.=L/C"
1440 PRINT "   (HLMSRI,STEP6; PDS3,P.9)"
1450 INPUT C1
1460 PRINT
1470 PRINT "IS C FACTØR IN TERMS ØF LL ØR TL ";
1480 INPUT A$
1490 PRINT
1500 IF A$="TL" THEN 1570
1510 IF A$="LL" THEN 1570
1520 GØTØ 1470
1530 LET P1=1/(C1*L1*L2*(5*L1↑2/384/E4+.15/A3/(.06*E3*1.03)))
1540 IF A$="TL" THEN 1620
1550 LET N1=P1
1560 GØTØ 1610
1570 PRINT "ENTER DESIGN DL (PSI) ";
1580 INPUT P9
1590 PRINT
1600 RETURN
1610 LET P1=P1+P9
1620 PRINT
1630 PRINT "STEP 5:"
1640 PRINT "P-SUB D = ";P1;"   PSI"
1650 IF A$="TL" THEN 1670
1660 PRINT "MADE UP ØF LL = ";N1;"   AND DL = ";P9;"   PSI"
1670 PRINT "PANEL DEFL.(MID-SPAN,SS) = ";L1/C1;"   IN."
1680 REM *********************
1690 REM * STEP 6  (HLMSRI) *
1700 REM *********************
1710 GØTØ 1780
1720 PRINT "STEP 6:"
1730 PRINT "ENTER I FØR TØP SKIN (STRESS PERPENDICULAR TØ STRNGERS)"
1740 PRINT "   (PDS,P.16,CØL.9)(IN.4/FT)"
1750 INPUT I8
1760 PRINT
1770 RETURN
1780 IF A$="TL" THEN 1810
1790 LET P7=384*E1*I8/12/C1/L4↑3+P9
1800 GØTØ 1820
1810 LET P7=384*E1*I8/12/C1/L4↑3
1820 PRINT
1830 PRINT "STEP 6:"
1840 PRINT "P-SUB T = ";P7;"   PSI"
1850 PRINT "   TØP-SKIN DEFL.BETW.STRINGERS = ";L4/C1;"   IN."
1860 PRINT
1870 REM *********************
1880 REM * STEP 7  (HLMSRI) *
1890 REM *********************
1900 GØTØ 1970
1910 PRINT "STEP 7:"
1920 PRINT "ENTER EFFECTIVE WIDTHS (AS FLANGES) ØF TØP, BØT.SKINS"
1930 PRINT "   (HLMSRI,FIG.3A; PDS3,P.10,RT.FIG.)"
1940 INPUT W1,W2
1950 PRINT
1960 RETURN
1970 LET N[5]=A1/12*W1+A2/12*W2+A3
1980 LET N[6]=A1/12*W1*E1*1.1+A2/12*W2*E2*1.1+A3*E3*1.03
1990 LET N[7]=A1/12*W1*E1*1.1*Y1+A2/12*W2*E2*1.1*Y2+A3*E3*1.03*Y3
2000 LET Y8=N[7]/N[6]
2010 PRINT "STEP 7:"
2020 PRINT "Y-BAR (BENDING N.A.) = ";Y8;"   IN."
2030 PRINT "HLMSRI FIG.3A 'TØTALS' (PLUS TØTAL ØF AREAS):"
2040 PRINT "    ",N[5],N[6],N[7]
2050 PRINT
2060 REM *********************
2070 REM * STEP 8  (HLMSRI) *
2080 REM *********************
2090 LET D4=Y1-Y8
2100 LET D5=Y8-Y2
2110 LET D6=ABS(Y8-Y3)
2120 LET N1=I1/12*W1+A1/12*W1*D4↑2
2130 LET N2=I2/12*W2+A2/12*W2*D5↑2
2140 LET N3=I3+A3*D6↑2
2150 LET I9=N1+N2+N3
2160 LET N4=E1*1.1*N1
2170 LET N5=E2*1.1*N2
2180 LET N6=E3*1.03*N3
2190 LET E5=N4+N5+N6
2200 PRINT "STEP 8:"
2210 PRINT "(EI-SUB N) = ";E5;"   LB-IN.2)"
2220 PRINT "HLMSRI FIG.3B 'TØTALS':",I9,E5
2230 REM *********************
2240 REM * STEP 9  (HLMSRI) *
2250 REM *********************
2260 GØTØ 2330
2270 PRINT "STEPS 9 & 10:"
2280 PRINT "ENTER TØP SKIN F-SUB C & BØT.SKIN F-SUB T (PSI)"
2290 PRINT "   (PDS,P.17)"
2300 INPUT F1,F2
2310 PRINT
2320 RETURN
2330 IF L4/B1 <= .5 THEN 2450
2340 IF L4/B1 <= 2 THEN 2380
2350 PRINT "WARNING: STRINGER SPACING SHØULD BE <= 2 B (SUB T ØR C)"
2360 PRINT "   (B VALUES FRØM STEP 2)"
2370 PRINT
2380 IF L4/B1 >= 1 THEN 2410
2390 LET F1=F1*(1-.333*2*(L4/B1-.5))
2400 GØTØ 2450
2410 LET F1=F1*.667
2420 REM **********************
2430 REM * STEP 10  (HLMSRI) *
2440 REM **********************
2450 IF L4/B2 <= .5 THEN 2570
2460 IF L4/B2 <= 2 THEN 2500
2470 PRINT "WARNING: STRINGER SPACING SHØULD BE <= 2 B (SUB T ØR C)"
2480 PRINT "   (B VALUES FRØM STEP 2)"
2490 PRINT
2500 IF L4/B2 >= 1 THEN 2530
2510 LET F2=F2*(1-.333*2*(L4/B2-.5))
2520 GØTØ 2570
2530 LET F2=F2*.667
2540 REM **********************
2550 REM * STEP 11  (HLMSRI) *
2560 REM **********************
```

Table 1 (continued)

```
2570 PRINT
2580 PRINT "STEPS 9 & 10:"
2590 PRINT "F-SUB C AND T,RESP'Y = ";F1;"   AND   ";F2;"   PSI"
2600 GØTØ 2660
2610 PRINT "STEP 11:"
2620 PRINT "ENTER ØVERALL PANEL THICKNESS (IN.) ";
2630 INPUT T1
2640 PRINT
2650 RETURN
2660 LET N1=8/(T1-Y6)/L2/L1↑2*E5/(E1*1.1)
2670 LET N2=8/Y8/L2/L1↑2*E5/(E2*1.1)
2680 LET N[9]=F1*N1
2690 LET N[10]=F2*N2
2700 IF N[9] <= N[10] THEN 2730
2710 LET P2=N[10]
2720 GØTØ 2740
2730 LET P2=N[9]
2740 PRINT
2750 PRINT "STEP 11:"
2760 PRINT "P-SUB B = ";P2;"   PSI"
2770 PRINT "TØP-SKIN = ";N[9];"   & BØT.SKIN = ";N[10];"   PSI"
2780 PRINT
2790 REM **********************
2800 REM * STEP 12  (HLMSRI) *
2810 REM **********************
2820 GØTØ 2930
2830 PRINT "STEP 12:"
2840 PRINT "ENTER AREA // PLIES ØUTSIDE CRITICAL PLANES,TØP&BØT."
2850 PRINT "   SKINS, RESP'Y (IN.2 / 48 IN.)"
2860 PRINT "   (2ND&6TH CØLS, HLMSRI FIG.4 AND PDS3 TABLE P.14)"
2870 INPUT A6,A7
2880 PRINT
2890 PRINT "ENTER Y-PRIME RELATED VALUES(SAME SØURCE,3RD&7TH CØLS,IN.)"
2900 INPUT Y9,Y0
2910 PRINT
2920 GØTØ 2960
2930 LET Q1=A6*(L2/48)*(T1-Y7-Y9)
2940 LET Q2=A7*(L2/48)*(Y7-Y0)
2950 GØTØ 3150
2960 PRINT "ENTER 3 STRINGER WIDTH TØTALS (IN.) IN FØLLØWING ØRDER,"
2970 PRINT "   SEPARATED BY CØMMAS:"
2980 PRINT "      UNGLUED (PRØTRUDING) STRINGER(S) WIDTH (TØTAL IN.),"
2990 PRINT "      GLUELINE (TØTAL IN.) WIDTH ØF EXTERIØR STRINGERS"
3000 PRINT "      WHØSE CLEAR DIST.TØ PANEL EDGE IS LESS THAN HALF"
3010 PRINT "      CLEAR DIST.BETW.STRINGERS,"
3020 PRINT "      GLUELINE (TØTAL IN.) WIDTH ØF ALL ØTHER STRINGERS."
3030 INPUT T2,T3,T4
3040 PRINT
3050 IF T5=T2+T3+T4 THEN 3100
3060 PRINT "SUM ØF STRINGER WIDTHS NØT EQUAL TØ 'TØTAL WIDTH ØF"
3070 PRINT "   STRINGERS' ENTERED UNDER STEP 4"
3080 PRINT
3090 GØTØ 2960
3100 PRINT "ENTER F-SUB S FØR TØP,BØT. SKINS, RESP'Y (PSI)"
3110 PRINT "   (PDS,P.17)"
3120 INPUT F3,F4
3130 PRINT
3140 RETURN
3150 LET N[11]=F3*(.5*T3+T4)
3160 LET N[12]=F4*(.5*T3+T4)
3170 REM    N(11) AND N(12) ARE SUMMATIØN F-SUB S TIMES T VALUES
3180 REM       FØR TØP AND BØTTØM SKINS, RESP'Y
3190 LET N[13]=2*N[11]/L1/L2/Q1*E4/(E1*1.1)
3200 LET N[14]=2*N[12]/L1/L2/Q2*E4/(E2*1.1)
3210 IF N[13]>N[14] THEN 3280
3220 LET P3=N[13]
3230 PRINT "STEP 12:"
3240 PRINT "TØP SKIN CØNTRØLS: P-SUB S = ";P3;"   PSI"
3250 PRINT "   (BØT.SKIN P-SUB S = ";N[14];"   PSI)"
3260 PRINT
3270 GØTØ 3360
3280 LET P3=N[14]
3290 PRINT "STEP 12:"
3300 PRINT "BØTTØM SKIN CØNTRØLS: P-SUB S = ";P3;"   PSI"
3310 PRINT "   (TØP SKIN P-SUB S = ";N[13];"   PSI)"
3320 PRINT
3330 REM **********************
3340 REM * STEP 13  (HLMSRI) *
3350 REM **********************
3360 LET Q4=A3*(1.5*(Y7-2*Y2))/(A3/T5)
3370 LET Q5=A2/[illegible]2*L2*(Y7-Y2)
3380 LET Q3=Q4+Q5*E2*1.1/(E3*1.03)
3390 GØTØ 3460
3400 PRINT "STEP 13:"
3410 PRINT "ENTER ALLØWABLE HØRIZ.SHEAR STRESS IN STRNGRS (PSI)"
3420 PRINT "   (NDS)"
3430 INPUT F5
3440 PRINT
3450 RETURN
3460 LET P4=2*F5*T5/(L1*L2*Q3)*(E4/(E3*1.03))
3470 PRINT "STEP 13:"
3480 PRINT "P-SUB V = ";P4;"   PSI"
3490 PRINT "Q-SUB V = ";Q3;"   IN.3"
3500 REM **********************
3510 REM * STEP 14  (HLMSRI) *
3520 REM **********************
3530 GØTØ 3640
3540 PRINT "STEP 14:"
3550 PRINT "ENTER ALLØWABLE STRESS IN BEARING ØN PLYWØØD BØT.FACE(PSI)"
3560 PRINT "   (PDS,P.17)"
3570 INPUT F6
3580 PRINT
3630 RETURN
3640 LET P5=P1
3650 IF P5 <= P2 THEN 3670
3660 LET P5=P2
3670 IF P5 <= P3 THEN 3690
3680 LET P5=P3
3690 IF P5 <= P4 THEN 3710
3700 LET P5=P4
3710 IF P5 <= P7 THEN 3730
3720 LET P5=P7
3730 PRINT
3740 PRINT "STEP 14:"
3750 PRINT "P-SUB M = ";P5;"   PSI"
3760 LET L3=L1/(2*(F6/P5-1))
3770 IF L3 >= 1.5 THEN 3800
3780 LET L3=1.5
3790 GØTØ 3840
3800 IF 2*L3-INT(2*L3)>.01 THEN 3630
```

Table 1 (continued)

```
3810 LET L3=INT(2*L3)/2
3820 GØTØ 3840
3830 LET L3=INT(2*L3+1/2)/2
3840 PRINT
3850 PRINT "L-SUB E = ";L3;"   IN."
3900 PRINT
3910 REM ***********************
3920 REM * STEP 15B  (HLMSRI) *
3930 REM ***********************
3940 PRINT "STEP 15:"
3950 PRINT "ØBSERVE PRESCRIBED MIN. LENGTHS FØR TENSIØN SPLICE-"
3960 PRINT "   PLATES(PDS,P.26 TABLE) & ØTHER LIMITATIØNS(HLMSRI)"
3970 PRINT
3980 GØTØ 4090
3990 PRINT "STEP 15:"
4000 PRINT "ENTER ALLØWABLE SPLICE-PLATE MAX.STRESS (PSI)"
4010 PRINT "   (PDS,P.26 TABLE)"
4020 INPUT F7
4030 PRINT
4040 PRINT "ENTER TØTAL LENGTH ØF SPLICE-PLATE ACRØSS PANEL (IN.)"
4050 PRINT "   (HLMSRI,STEP 15B; PDS3,P.4 FIG.)"
4060 INPUT L5
4070 PRINT
4080 RETURN
4090 IF L5<L2 THEN 4130
4100 PRINT "SPLICE-PLATE LENGTH MUST BE SHØRTER THAN PANEL WIDTH"
4110 PRINT
4120 GØSUB 4040
4130 LET P6=8*(F7*L5/L2)/Y7/L2/L1+2*E4/(E2*1.1)
4140 PRINT "P-SUB P = ";P6;"   PSI"
4150 PRINT "IF P-SUB P < P-SUB M (";P5;") ØR DESIGN TL, WHICHEVER"
4160 PRINT "   CRITERIØN IS USED, SPLICE-PLATE SHØULD BE REDESIGNED"
4170 PRINT "   ØR RELØCATED (P-SUB P CALC'D ØN MID-SPAN LØCATIØN)"
4180 GØSUB 5000
4190 PRINT "RUN ANØTHER PRØBLEM (YES ØR NØ) "
4200 INPUT B$
4210 IF B$="NØ" THEN 9999
4220 GØSUB 5000
4230 GØTØ 200
4240 GØSUB 5000
4250 PRINT "STEP"
4260 PRINT "  2","TØP B","BØTTØM B","CL.DIST.BETW.STRNGR'S"
4270 PRINT "   ",B1,B2,L4
4280 PRINT
4290 PRINT "  3","E TØP SKIN","E BØT.SKIN","E STRNGRS","A// TØP"
4300 PRINT "   ",E1,E2,E3,A1
4310 PRINT "   ","A// BØT.SKIN","AREA STRNGRS","TP.SK.MØM.ARM","BØT.DITTØ"
4320 PRINT "   ",A2,A3,Y1,Y2
4330 PRINT "   ","MØM.ARM STR'S","PANEL WIDTH (PLYWØØD)"
4340 PRINT "   ",Y3,L2
4350 PRINT
4360 PRINT "  4","I TØP SK.","I BØT.SK.","TØTAL WIDTH STRNGR'S"
4370 PRINT "   ",I1,I2,T5
4380 PRINT
4390 PRINT "  5","PANEL CL.SP.","C FACTØR","C IN LL ØR TL?"
4400 PRINT "   ",L1,C1,A$
4410 PRINT
4420 IF A$="TL" THEN 4470
4430 PRINT "  6","DESIGN DL","I TØP SK.(STRESS PERPEND. TØ STR'S)"
4440 PRINT "   ",P9,I8
4450 PRINT
4460 GØTØ 4500
4470 PRINT "  6","I TØP SK.(STRESS PERPEND. TØ STRINGERS)"
4480 PRINT "   ",I8
4490 PRINT
4500 PRINT "  7","TØP SKIN","& BØT. SKIN","EFFECTIVE WIDTHS"
4510 PRINT "   ",W1,W2
4520 PRINT
4530 PRINT " 9&10","TØP SK.F-SUB C","BØT.SK.F-SUB T"
4540 PRINT "   ",F1,F2
4550 PRINT
4560 PRINT " 11","ØVERALL PANEL THICKNESS"
4570 PRINT "   ",T1
4580 PRINT
4590 PRINT " 12","TØP SK.A//","& BØT.SK.A//","BØTH ØUTSIDE CRITICAL PL."
4600 PRINT "   ",A6,A7
4610 PRINT "   ","RELATED Y-PRIME VALUES"
4620 PRINT "   ",Y9,Y0
4630 PRINT "   ","UNGLUED","& EXT.GLUED","& INT. GLUED",
4640 PRINT "STRNK WIDTHS"
4650 PRINT "   ",T2,T3,T4
4660 PRINT "   ","TØP SK.F-SUB S","BØT.SK.F-SUB S"
4670 PRINT "   ",F3,F4
4680 PRINT
4690 PRINT " 13","ALLØW.HØRIZ.SHEAR STRESS, STRINGERS"
4700 PRINT "   ",F5
4710 PRINT
4720 PRINT " 14","PLYW.BØT.FACE ALLØW.BEAR.STRESS"
4730 PRINT "   ","   ",F6
4740 PRINT
4750 PRINT " 15","ALLØW.SPL-PL.MAX.STRESS","TØTAL X-PANEL SPL-PL.LENGTH"
4760 PRINT "   ",F7,"   ",L5
4770 RETURN
5000  FØR N9=1 TØ 5
5010  PRINT
5020  NEXT N9
5030 RETURN
9999 END
```

Table 1 (continued)

```
RUN
HLMPSP

STEP 2:
ENTER 'B' DISTANCES FØR TØP & BØT. SKINS, RESP'Y(IN.)
    (HLMSRI, FIG.1B; ALSØ PDS3, P.5(TABLE))
?32.12

ENTER CLEAR DISTANCE BETWEEN STRNGRS (FIG.1A,HLMSRI)(IN.)
    (SHØULD BE UNIFØRM; IF NØT, USE LARGEST VALUE)
?13.9

STEP 3:
ENTER E VALUES (PSI) FØR TØP,BØT.SKINS & STRINGERS,RESP'Y
    (PDS,P.17 & NDS)
?1800000,1800000,1800000

ENTER A// VALUES FØR TØP,BØT.SKINS (SQ IN/FT WIDTH)
    (PDS,P.16,CØL.4)
?2.728,1.914

ENTER TØTAL X-SECT.AREA ØF ALL STRINGERS (SQ IN)
?32.2

ENTER MØMENT ARMS FØR TØP,BØT.SKINS & STRNGRS,RESP'Y(IN.)
    (FRØM BØTTØM SURFACE ØF PANEL)
?6,.156,3

ENTER WIDTH (PLYWØØD) ØF PANEL (IN.)?48

STEP 4:
ENTER I ØF TØP,BØT.SKINS ABØUT ØWN AXES(IN.4/FT WIDTH)
    (PDS,P.16,CØL.5)
?.141,.025

ENTER TØTAL WIDTH ØF STRINGERS (IN.) ?6

STEP 5:
ENTER CLEAR SPAN L ØF PANEL (IN.) ?168

ENTER C FACTØR, IN MAX.ALLØWABLE DEFL.=L/C
    (HLMSRI,STEP6; PDS3,P.9)
?360

IS C FACTØR IN TERMS ØF LL ØR TL ?LL

ENTER DESIGN DL (PSI) ?.0694444

STEP 6:
ENTER I FØR TØP SKIN (STRESS PERPENDICULAR TØ STRNGERS)
    (PDS,P.16,CØL.9)(IN.4/FT)
?.023

STEP 7:
ENTER EFFECTIVE WIDTHS (AS FLANGES) ØF TØP, BØT.SKINS
    (HLMSRI,FIG.3A; PDS3,P.10,RT.FIG.)
?48,42.3

STEPS 9 & 10:
ENTER TØP SKIN F-SUB C & BØT.SKIN F-SUB T (PSI)
    (PDS,P.17)
?1540,1650

STEP 11:
ENTER ØVERALL PANEL THICKNESS (IN.) ?6.312

STEP 12:
ENTER AREA // PLIES ØUTSIDE CRITICAL PLANES,TØP&BØT.
    SKINS, RESP'Y (IN.2 / 48 IN.)
    (2ND&6TH CØLS, HLMSRI FIG.4 AND PDS3 TABLE P.14)
?6.06,3.83

ENTER Y-PRIME RELATED VALUES(SAME SØURCE,3RD&7TH CØLS,IN.)
?.146,.0479

ENTER 3 STRINGER WIDTH TØTALS (IN.) IN FØLLØWING ØRDER,
    SEPARATED BY CØMMAS:
        UNGLUED (PRØTRUDING) STRINGER(S) WIDTH (TØTAL IN.),
        GLUELINE (TØTAL IN.) WIDTH ØF EXTERIØR STRINGERS
        WHØSE CLEAR DIST.TØ PANEL EDGE IS LESS THAN HALF
        CLEAR DIST.BETW.STRINGERS,
        GLUELINE (TØTAL IN.) WIDTH ØF ALL ØTHER STRINGERS.
?.75,2.25,3

ENTER F-SUB S FØR TØP,BØT. SKINS, RESP'Y (PSI)
    (PDS,P.17)
?48,48

STEP 13:
ENTER ALLØWABLE HØRIZ.SHEAR STRESS IN STRNGRS (PSI)
    (NDS)
?95

STEP 14:
ENTER ALLØWABLE STRESS IN BEARING ØN PLYWØØD BØT.FACE(PSI)
    (PDS,P.17)
?340

STEP 15:
ENTER ALLØWABLE SPLICE-PLATE MAX.STRESS (PSI)
    (PDS,P.26 TABLE)
?1200

ENTER TØTAL LENGTH ØF SPLICE-PLATE ACRØSS PANEL (IN.)
    (HLMSRI,STEP 15B; PDS3,P.4 FIG.)
?40.2

ANY CHANGES DESIRED (YES ØR NØ)
?NØ

WANT TABULATIØN ØF INPUT VALUES (YES ØR NØ)
?YES
```

Table 1 (concluded)

```
STEP
 2       TØP B            BØTTØM B          CL.DIST.BETW.STRNGR'S
           32               12                13.9

 3       E TØP SKIN       E BØT.SKIN        E STRNGRS        A// TØP
           1.80000E+06      1.80000E+06       1.80000E+06      2.726
         A// BØT.SKIN     AREA STRNGRS      TP.SK.MØM.ARM    BØT.DITTØ
           1.914            32.2              6                .156
         MØM.ARM STR'S    PANEL WIDTH (PLYWØØD)
           3                48

 4       I TØP SK.        I BØT.SK.         TØTAL WIDTH STRNGR'S
           .141             .025              6

 5       PANEL CL.SP.     C FACTØR          C IN LL ØR TL?
           168              360               LL

 6       DESIGN DL        I TØP SK.(STRESS PERPEND. TØ STR'S)
           6.94444E-02      .023

 7       TØP SKIN         & BØT. SKIN       EFFECTIVE WIDTHS
           48               42.3

 9&10    TØP SK.F-SUB C BØT.SK.F-SUB T
           1540             1650

 11      ØVERALL PANEL THICKNESS
           6.312

 12      TØP SK.A//       & BØT.SK.A//      BØTH ØUTSIDE CRITICAL PL.
           6.06             3.83
         RELATED Y-PRIME VALUES
           .148             .0479
         UNGLUED          & EXT.GLUED       & INT. GLUED     STRNR WIDTHS
           .75              2.25              3
         TØP SK.F-SUB S BØT.SK.F-SUB S
           48               48

 13      ALLØW.HØRIZ.SHEAR STRESS, STRINGERS
           95

 14      PLYW.BØT.FACE ALLØW.BEAR.STRESS
                            340

 15      ALLØW.SPL-PL.MAX.STRESS            TØTAL X-PANEL SPL-PL.LENGTH
           1200                               40.2


ANY CHANGES DESIRED (YES ØR NØ)
?NØ

WANT TABULATIØN ØF INPUT VALUES (YES ØR NØ)
?NØ
```

```
STEP 3:
Y-BAR (DEFLECTIØN N.A.) =  3.22501         IN.
HLMSRI FIG.2A 'TØTALS':          50.768          9.64634E+07     3.11096E+08

STEP 4:
(EI-SUB G) =  4.56775E+08         LB-IN.2
HLMSRI FIG.2B 'TØTALS':          235.716         4.56775E+08

STEP 5:
P-SUB D =  .476406         PSI
MADE UP ØF LL =  .406964          AND DL =  6.94444E-02        PSI
PANEL DEFL.(MID-SPAN,SS) =  .466667          IN.

STEP 6:
P-SUB T =  1.43971         PSI
   TØP-SKIN DEFL.BETW.STRINGERS =  3.86111E-02        IN.

STEP 7:
Y-BAR (BENDING N.A.) =  3.28337          IN.
HLMSRI FIG.3A 'TØTALS' (PLUS TØTAL ØF AREAS):
        49.8588             9.46633E+07      3.10615E+08

STEP 8:
(EI-SUB N) =  4.39474E+08         LB-IN.2)
HLMSRI FIG.3B 'TØTALS':          227.039         4.39474E+08

STEPS 9 & 10:
F-SUB C AND T,RESP'Y =  1540        AND      1100.55          PSI

STEP 11:
P-SUB B =  .439327         PSI
TØP-SKIN =  .666459          & BØT.SKIN =  .439327         PSI

STEP 12:
TØP SKIN CØNTRØLS: P-SUB S =  .63608          PSI
   (BØT.SKIN P-SUB S =  .931003          PSI)

STEP 13:
P-SUB V =  .678801         PSI
Q-SUB V =  51.3103         IN.3

STEP 14:
P-SUB M =  .439327         PSI

L-SUB E =  1.5          IN.

STEP 15:
ØBSERVE PRESCRIBED MIN. LENGTHS FØR TENSIØN SPLICE-
   PLATES(PDS,P.26 TABLE) & ØTHER LIMITATIØNS(HLMSRI)

P-SUB P =  .424524         PSI
IF P-SUB P < P-SUB M ( .439327     ) ØR DESIGN TL, WHICHEVER
   CRITERIØN IS USED, SPLICE-PLATE SHØULD BE REDESIGNED
   ØR RELØCATED (P-SUB P CALC'D ØN MID-SPAN LØCATIØN)


RUN ANØTHER PRØBLEM (YES ØR NØ)
?NØ
```

Table 2 CATALOG OF PSSP PRE-DESIGNS

STRINGERS: 2"x4" (1.5"x 3.5") — Panel width: 48"

p_{dm} Vs. Clear Span

PLYWOOD top/bot. skin		stringers	Low str. (F_v/E) 280/1000000 24"	Low str. (F_v/E) 280/1000000 96"	Avg. 330/1250000 96"	High str. (F_v/E) 380/1500000 24"	High str. (F_v/E) 380/1500000 96"
1/2 & 1/2	#1	4	7.21 (psi)	1.80	2.04	9.09	2.27
Underlay.-		7	11.35	2.84	3.18	14.02	3.50
Interior		9	13.79	3.45	3.85	16.91	4.23
	#3	4	6.70	1.67	1.88	8.32	2.08
		7	10.33	2.58	2.88	12.63	3.13bt
		9	12.46	2.98bt	3.20bt	15.20	3.42bt
5/8 & 1/2	#1	4	7.36	1.84	2.09	9.27	2.32
Underlay.-		5	8.85	2.21	2.50	11.06	2.76
Interior		7	11.58	2.90	3.24	14.29	3.57
		9	14.06	3.52	3.92	17.23	4.31
	#3	4	6.83	1.71	1.92	8.48	2.12
		5	8.15	2.04	2.28	10.03	2.51
		7	10.53	2.63	2.89bt	12.86	3.06bt
		9	12.70	2.92bt	3.13bt	15.46	3.34bt
3/4 & 1/2	#1	4	7.63st&v	1.91st&v	1.94st	7.92st	1.98st
Underlay.-		7	12.10	3.02	3.40	14.98	3.75
Interior		9	14.72	3.68	4.11	18.08	4.52
	#3	4	7.13	1.78	2.01	8.38st	2.09st
		7	11.04	2.76	3.08	13.50	3.29bt
		9	13.32	3.16bt	3.35bt	16.21	3.55bt
3/4 & 3/4	#1	4	7.97	1.99	2.07st&sb	8.47st&sb	2.12st&sb
Underlay.-		7	12.69	3.17	3.57	15.75	3.94
Interior		9	15.46	3.87	4.32	19.02	4.75
	#3	4	7.47	1.87	2.11	8.98st&sb	2.25st&sb
		7	11.60	2.90	3.23	14.20	3.54bt&v
		9	14.01	3.41bt	3.61bt	17.04	3.81bt

* Lower case letters following p_{dm}(psi) values indicate mode of failure (or least strength value) that is the basis for the p_{dm} value, as follows: no letter(s) = horizontal shear, v; bt = bending-top skin (i.e., compression in blastward plywood skin); bb = bending-bottom skin (i.e., tension failure); st or sb = rolling shear failure in top or bottom skin, respectively.

Tables 2 and 4 are research designs used for cross-checks and to construct successively simpler charts that follow. Decimal places shown do not imply accuracy (guesstimated at ±20%), but are for check-points for user design work and for correlation checks with any prototype testing to destruction, as recommended at end of Appendix.

Table 2 (continued)

P_{dm} Vs. Clear Span — STRINGERS: 2"x4" (1.5"x 3.5") — Panel width: 48"

PLYWOOD	Low Strength (F_y/E) 280/1000000						Avg. 330/1250000			High Strength (F_y/E) 380/1500000					
	24"			144"			96"			24"			144"		
top/bot.skin	4	7	9 stringers	4	7	9	4	7	9	4	7	9	4	7	9
1-1/8 & 1/2 #1&#1	7.36s: (psi)			1.23st			1.85st			7.47st			1.25st		
2.4.1		13.43			2.24			3.79			15.64st			2.45bt	
Interior &			16.43			2.41bt			4.61			20.32			2.54bt
Underlay.- #1 &	6.94st			1.16st			1.74st			7.02st			1.17st		
Interior #3		13.13			1.99bb			3.60st			14.68st			2.27bb	
			16.02			2.15bb			4.48			19.74			2.37bt
1-1/8 & 3/4 #1&#1	7.81st			1.30st			1.97st			7.96st			1.33st		
(Ibid.)		13.95			2.33			3.94			16.68st			2.64bt	
			17.10			2.59bt			4.80			21.17			2.73bt
#1&#3	7.37st			1.23st			1.85st			7.46st			1.24st		
		13.60			2.14bb			3.82st&v			15.56st			2.38bb	
			16.61			2.28bb			4.65			20.46			2.52bt
1-1/8 & 1-1/8 #1	8.58st&sb			1.43st&sb			2.17st&sb			8.81st&sb			1.47st&sb		
2.4.1		14.90			2.48			4.22			18.63st&sb			2.98bt	
Interior			18.32			2.93bt			5.16			22.79			3.09bt

Table 2 (continued)

P_{dm} Vs. Clear Span | STRINGERS: 2"x6" (1.5"x 5.5") | Panel width: 48"

PLYWOOD top/bot.skin		Low Strength (F_y/E) 280/1100000 24" 4	7	9 stringers	144" 4	7	9	Avg. 330/1450000 96" 4	7	9	High Strength (F_y/E) 380/1800000 24" 4	7	9	144" 4	7	9
1/2 & 1/2 Underlay.- Interior	#1	11.40 (psi)	18.63	23.14	1.90	3.11	3.45bt	3.25	5.28	6.55	14.58	23.60	29.26	2.43	3.78bt	4.23bt
	#3	10.87	17.61	21.83	1.78bt	2.35bt	2.61bt	3.09	4.98	6.18	13.79	22.26	27.65	2.08bt	2.93bt	3.36bt
5/8 & 1/2 Underlay.- Interior	#1	11.55	18.87	23.42	1.93	3.14	3.40bt	3.30	5.35	6.63	14.77	23.87	29.56	2.46	3.72bt	4.15bt
	#3	11.01	17.81	22.07	1.83	2.31bt	2.56bt	3.12	5.04	6.24	13.95	22.48	27.90	2.25bt	2.87bt	3.28bt
3/4 & 1/2 Underlay.- Interior	#1	11.98	19.64	24.39	2.00	3.27	3.67bt	3.26st	5.57	6.89	13.65st	24.83	30.71	2.28st	3.97bt	4.38bt
	#3	11.45	18.54	22.94	1.91	2.48bt	2.72bt	3.25	5.24	6.47	14.52	23.32	28.86	2.42	3.01bt	3.41bt
3/4 & 3/4 Underlay.- Interior	#1	12.13	19.87	24.68	2.02	3.31	3.89bt	3.44st&sb	5.64	6.98	14.42st&sb	25.14	31.10	2.40st&sb	4.19	4.61bt
	#3	11.58	18.77	23.22	1.93	2.62bt	2.86bt	3.29	5.30	6.56	14.70	23.61	29.21	2.45	3.16bt	3.56bt

Table 2 (continued)

P_{dm} Vs. Clear Span — STRINGERS: 2"x6" (1.5"x 5.5") — Panel width: 48"

PLYWOOD top/bot.skin		Low Strength (F_v/E) 280/1100000, 24", 4	7	9 stringers	144", 4	7	9	Avg. 330/1450000, 96", 4	7	9	High Strength (F_v/E) 380/1800000, 24", 4	7	9	144", 4	7	9
1-1/8 & 1/2	#1 &	11.54st (psi)			1.92st			2.97st			12.21st			2.04st		
2.4.1	#1		21.50			3.58			6.11			27.24			4.50bt	
Interior &				26.74			4.24bt			7.56			33.62			4.85bt
Underlay.-	#1 &	10.87st			1.81st			2.79st			11.50st			1.92st		
Interior	#3		21.81			3.61bb			6.14st			25.92st			4.24bt	
				27.07			3.98bt			7.63			33.83			4.59bt
1-1/8 & 3/4	#1 &	12.13st			2.02st			3.12st			12.85st			2.14st		
(Ibid.)	#1		21.64			3.61			6.15			27.43			4.57	
				26.92			4.48			7.62			33.88			5.10bt
	#1 &	11.42st			1.90st			2.93st			12.05st			2.01st		
	#3		21.90			3.65			6.21			27.01st			4.43bt	
				27.18			4.16bb			7.67			34.02			4.78bt
1-1/8 & 1-1/8	#1	13.16st&sb			2.19st&sb			3.40st&sb			14.03st&sb			2.34st&sb		
2.4.1			21.98			3.66			6.25			27.90			4.65	
Interior				27.36			4.56			7.75			34.49			5.59bt

Table 2 (continued)

P_{dm} Vs. Clear Span — STRINGERS: 2"x8" (1.5"x 7.25") — Panel width: 48"

PLYWOOD top/bot.skin	stringers	Low strength (F_v/E) 280/1100000, 24"	Low strength (F_v/E) 280/1100000, 144"	Avg. 330/1450000, 96"	High Strength (F_v/E) 380/1800000, 24"	High Strength (F_v/E) 380/1800000, 144"
1-1/8 & 1/2 #1	4	15.55st	2.59st	4.05st	16.91st	2.82st
2.4.1 & #1	7	30.10	5.02	8.68	39.24	6.54
Interior &	9	37.98	6.15bt	10.92	49.22	7.31bt
Underlay.- #1	4	14.67st	2.45st	3.83st	15.99st	2.66st
Interior & #3	7	31.29	5.22	8.75st	37.64st	6.27st
	9	39.34	5.81bt	11.25	50.54	6.98bt
1-1/8 & 3/4 #1	4	16.27st	2.71st	4.24st	17.69st	2.95st
2.4.1 & #1	7	29.76	4.96	8.59	38.84	6.47
Interior &	9	37.56	6.26	10.81	48.78	7.61bt
Underlay.- #1	4	15.31st	2.55st	3.99st	16.63st	2.77st
Interior & #3	7	30.89	5.15	8.89	38.92st	6.49st
	9	38.87	6.03bt	11.14	50.12	7.20bt
1-1/8 & 1-1/8 #1	4	17.36	2.89	4.58st&sb	19.14st&sb	3.19st&sb
2.4.1 & #1	5	21.43	3.57	6.20	26.89st&sb	4.48st&sb
Interior	7	29.35	4.89	8.47	38.32	6.39
	9	37.03	6.17	10.66	48.19	8.03

NOTE: PSSP designs with 2"x 8" stringers, as shown on this page, used actual dimensions of 1.5"x 7.25" - but those designs with 2"x 8" stringers shown on pages A1-25 and A1-37 (Table 4) erroneously used actual dimensions of 1.5"x 7.5" so should be disregarded. These slightly erroneous designs have been, however, retained for comparing PSSP designs using various types and grades of plywood.

Table 2 (concluded)

P_{dm} Vs. Clear Span — STRINGERS: 2"x8" (1.5"x 7.5") — Panel width: 48"

PLYWOOD top/bot.skin		Low str. (F_y/E) 280/1100000 24" 4	5	7	9stringers	144" 4	5	7	9	Avg. 330/1450000 96" 4	5	7	9	High strength (F_y/E) 380/1800000 24" 4	5	7	9	144" 4	5	7	9
1-1/8 & 1/2	#1 &	16.15st (psi)				2.69st				4.22st				17.63st				2.94st			
2.4.1	#1		22.28st				3.71st				5.88st				24.84st				4.14st		
Interior &				31.43				5.24				9.09				41.12				6.85	
Underlay.-					39.72				6.44bt				11.44				51.68				7.70bt
Interior	#1 & #3	15.24st				2.54st				3.98st				16.67st				2.78st			
			21.04st				3.51st				5.57st				23.56st				3.93st		
				32.77				5.46				9.16st				39.48st				6.58st	
					41.26				6.09bt				11.83				53.20				7.36bt
1-1/8 & 3/4	#1 &	16.89st				2.81st				4.41st				18.42st				3.07st			
2.4.1	#1		22.55				3.76				6.15st				25.94st				4.32st		
Interior &				31.01				5.17				8.97				40.62				6.77	
Underlay.-					39.20				6.53				11.31				51.13				8.01bt
Interior	#1 & #3	15.90st				2.65st				4.15st				17.33st				2.89st			
			21.92st				3.65st				5.79st				24.43st				4.07st		
				32.28				5.38				9.31				40.78st				6.80st	
					40.70				6.32bt				11.69				52.67				7.58bt
1-1/8 & 1-1/8	#1 &	17.96				2.99				4.76st&sb				19.91st&sb				3.32st&sb			
2.4.1	#1		22.20				3.70				6.44				28.03st&sb				4.67st&sb		
Interior				30.47				5.08				8.81				39.93				6.66	
					38.52				6.42				11.12				50.33				8.39

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Table 3 LISTING OF COMPUTER PROGRAMS (HMPSP2 AND 3) USED FOR PRE-DESIGNS (TABLES 2 AND 4)

```
LIS
HMPSP2

0050 REM    THIS PROGRAM IS A MODIFICATION AND EXTENSION OF HLMPSP,
0052 REM    SO THAT MULTIPLE DESIGNS MAY BE RUN:
0054 REM
0100 REM    PROGRAM FOR DESIGN OF PLYWOOD STRESSED-SKIN PANELS
0102 REM
0104 REM    PDS = PLYWOOD DESIGN SPEC.,AMER.PLYWOOD ASSN (REV.1/76)
0106 REM    PDS3= SUPPLEMENT 3 (1974) TO PDS
0108 REM    NDS = NATL DES. SPEC. FOR STRESS-GRADE LUMBERS AND ITS
0109 REM      FASTENINGS, TABLE 1 (SUPPLEMENT,REV.11/74)
0112 REM    WDHDBK = WOOD HANDBOOK REV.8/74,U.S.FOREST PRODUCTS LAB
0114 REM    HLMSRI = H.L.MURPHY REPORT DESCRIPTION OF DESIGN PROCEDURE
0116 REM
0120 DIM N[20],A$[10]
0121 DIM B$[10],C$[10],D$[10],E$[20]
0130 GOSUB 210
0134 GOSUB 310
0136 GOSUB 330
0138 GOSUB 350
0140 GOSUB 370
0144 GOSUB 510
0146 GOSUB 530
0148 GOSUB 710
0152 GOSUB 820
0156 GOSUB 950
0160 GOSUB 1410
0162 GOSUB 1620
0164 GOSUB 1710
0168 GOSUB 1820
0170 GOSUB 1940
0172 GOSUB 2010
0178 LET L2=48
0182 LET C1=360
0184 LET A$="LL"
0186 LET W1=W2=48
0188 LET T2=0
0190 LET T3=3
0191 GOSUB 5040
0192 LET T4=T5-T2-T3
0194 LET T6=1.5
0196 LET L4=(L2-T5)/(T5/1.5-1)
0197 LET N[19]=F1
0198 LET N[20]=F2
0200 REM ********************
0201 REM * STEP 2  (HLMSRI) *
0202 REM ********************
0209 GOTO 250
0210 PRINT "ENTER 'B' DISTANCES FOR TOP & BOT. SKINS, RESP'Y(IN.)"
0211 PRINT "   (HLMSRI, FIG.1B; ALSO PDS3, P.5(TABLE))"
0220 INPUT B1,B2
0221 PRINT
0222 RETURN
0230 PRINT "ENTER CLEAR DISTANCE BETWEEN STRNGRS (FIG.1A,HLMSRI)(IN.)"
0231 PRINT "   (SHOULD BE UNIFORM; IF NOT, USE LARGEST VALUE)"
0240 INPUT L4
0241 PRINT
0242 RETURN
0250 IF L4 <= 2*B1 THEN 309
0260 IF L4 <= 2*B2 THEN 309
0270 PRINT "WARNING: PROGRAM DESIGN PROCEDURE NOT APPLICABLE"
0271 PRINT "   (HLMSRI, STEP 2; ALSO PDS3,SEC.2.2.1.1,P.5)"
0272 PRINT
0300 REM ********************
0301 REM * STEP 3  (HLMSRI) *
0302 REM ********************
0309 GOTO 410
0310 PRINT "ENTER E VALUES (PSI) FOR TOP,BOT.SKINS & STRINGERS,RESP'Y"
0311 PRINT "   (PDS,P.17 & NDS)"
0320 INPUT E1,E2,E3
0321 PRINT
0322 RETURN
0330 PRINT "ENTER A// VALUES FOR TOP,BOT.SKINS (SQ IN/FT WIDTH)"
0331 PRINT "   (PDS,P.16,COL.4)"
0340 INPUT A1,A2
0341 PRINT
0342 RETURN
0350 PRINT "ENTER TOTAL X-SECT.AREA OF ALL STRINGERS (SQ IN)"
0360 INPUT A3
0361 PRINT
0362 RETURN
0370 PRINT "ENTER MOMENT ARMS FOR TOP,BOT.SKINS & STRNGRS,RESP'Y(IN.)"
0371 PRINT "   (FROM BOTTOM SURFACE OF PANEL)"
0380 INPUT Y1,Y2,Y3
0381 PRINT
0382 RETURN
0390 PRINT "ENTER WIDTH (PLYWOOD) OF PANEL (IN.)";
0400 INPUT L2
0401 PRINT
0402 RETURN
0410 LET N[1]=A1/12*L2+A2/12*L2+A3
0420 LET N[2]=A1/12*L2*E1*1.1+A2/12*L2*E2*1.1+A3*E3*1.03
0430 LET N[3]=A1/12*L2*E1*1.1*Y1+A2/12*L2*E2*1.1*Y2+A3*E3*1.03*Y3
0440 LET Y7=N[3]/N[2]
0500 REM ********************
0501 REM * STEP 4  (HLMSRI) *
0502 REM ********************
0509 GOTO 550
0510 PRINT "ENTER I OF TOP,BOT.SKINS ABOUT OWN AXES(IN.4/FT WIDTH)"
0511 PRINT "   (PDS,P.16,COL.5)"
0520 INPUT I1,I2
0521 PRINT
0522 RETURN
0530 PRINT "ENTER TOTAL WIDTH OF STRINGERS (IN.) ";
0540 INPUT T5
0541 PRINT
0542 RETURN
0550 LET I3=T5*(A3/T5)^3/12
0560 LET D1=Y1-Y7
0570 LET D2=Y7-Y2
0580 LET D3=ABS(Y7-Y3)
0590 LET N1=I1/12*L2+A1/12*L2*D1^2
0600 LET N2=I2/12*L2+A2/12*L2*D2^2
0610 LET N3=I3+A3*D3^2
0620 LET I7=N1+N2+N3
0630 LET N4=E1*1.1*N1
0640 LET N5=E2*1.1*N2
0650 LET N6=E3*1.03*N3
0660 LET E4=N4+N5+N6
0700 REM ********************
0701 REM * STEP 5  (HLMSRI) *
```

Table 3 (continued)

```
0702 REM ********************
0709 GOTO 722
0710 PRINT "ENTER CLEAR SPAN L OF PANEL (IN.) ";
0716 INPUT L1
0717 PRINT
0720 RETURN
0722 IF L1-INT(L1)<.01 THEN 728
0724 LET L1=INT(L1)+1
0726 GOTO 729
0728 LET L1=INT(L1)
0729 GOTO 770
0730 PRINT "ENTER C FACTOR, IN MAX.ALLOWABLE DEFL.=L/C"
0731 PRINT "   (HLMSRI,STEP6; PDS3,P.9)"
0740 INPUT C1
0741 PRINT
0750 PRINT "IS C FACTOR IN TERMS OF LL OR TL ";
0760 INPUT A$
0761 PRINT
0762 RETURN
0770 IF A$="TL" THEN 800
0780 IF A$="LL" THEN 800
0790 GOSUB 750
0800 LET P1=1/(C1*L1*L2*(5*L1^2/384/E4+.15/A3/(.06*E3*1.03)))
0810 IF A$="TL" THEN 889
0815 LET N1=P1
0819 GOTO 840
0820 PRINT "ENTER DESIGN DL (PSI) ";
0830 INPUT P9
0831 PRINT
0832 RETURN
0840 LET P1=P1+P9
0889 PRINT
0900 REM ********************
0901 REM * STEP 6  (HLMSRI) *
0902 REM ********************
0909 GOTO 970
0950 PRINT "ENTER I FOR TOP SKIN (STRESS PERPENDICULAR TO STRNGERS)"
0951 PRINT "   (PDS,P.16,COL.9)(IN.4/FT)"
0960 INPUT I8
0961 PRINT
0962 RETURN
0970 IF A$="TL" THEN 1000
0980 LET P7=384*E1*I8/12/C1/L4^3+P9
0990 GOTO 1009
1000 LET P7=384*E1*I8/12/C1/L4^3
1009 PRINT
1100 REM ********************
1101 REM * STEP 7  (HLMSRI) *
1102 REM ********************
1109 GOTO 1150
1110 PRINT "ENTER EFFECTIVE WIDTHS (AS FLANGES) OF TOP, BOT.SKINS"
1111 PRINT "   (HLMSRI,FIG.3A; PDS3,P.10,RT.FIG.)"
1120 INPUT W1,W2
1121 PRINT
1122 RETURN
1150 LET N[5]=A1/12*W1+A2/12*W2+A3
1160 LET N[6]=A1/12*W1*E1*1.1+A2/12*W2*E2*1.1+A3*E3*1.03
1170 LET N[7]=A1/12*W1*E1*1.1*Y1+A2/12*W2*E2*1.1*Y2+A3*E3*1.03*Y3
1180 LET Y8=N[7]/N[6]
1200 REM ********************
1201 REM * STEP 8  (HLMSRI) *
1202 REM ********************
1210 LET D4=Y1-Y8
1215 LET D5=Y8-Y2
1220 LET D6=ABS(Y8-Y3)
1230 LET N1=I1/12*W1+A1/12*W1*D4^2
1240 LET N2=I2/12*W2+A2/12*W2*D5^2
1250 LET N3=I3+A3*D6^2
1260 LET I9=N1+N2+N3
1270 LET N4=E1*1.1*N1
1280 LET N5=E2*1.1*N2
1290 LET N6=E3*1.03*N3
1300 LET E5=N4+N5+N6
1400 REM ********************
1401 REM * STEP 9  (HLMSRI) *
1402 REM ********************
1409 GOTO 1430
1410 PRINT "ENTER TOP SKIN F-SUB C & BOT.SKIN F-SUB T (PSI)"
1411 PRINT "   (PDS,P.17)"
1420 INPUT F1,F2
1423 PRINT
1429 RETURN
1430 IF L4/B1 <= .5 THEN 1510
1440 IF L4/B1 <= 2 THEN 1450
1441 PRINT "WARNING: STRINGER SPACING SHOULD BE <= 2 B (SUB T OR C)"
1442 PRINT "   (B VALUES FROM STEP 2)"
1443 PRINT
1450 IF L4/B1 >= 1 THEN 1480
1460 LET F1=F1*(1-.333*2*(L4/B1-.5))
1470 GOTO 1510
1480 LET F1=F1*.667
1500 REM ********************
1501 REM * STEP 10  (HLMSRI) *
1502 REM ********************
1510 IF L4/B2 <= .5 THEN 1610
1520 IF L4/B2 <= 2 THEN 1530
1521 PRINT "WARNING: STRINGER SPACING SHOULD BE <= 2 B (SUB T OR C)"
1522 PRINT "   (B VALUES FROM STEP 2)"
1523 PRINT
1530 IF L4/B2 >= 1 THEN 1560
1540 LET F2=F2*(1-.333*2*(L4/B2-.5))
1550 GOTO 1610
1560 LET F2=F2*.667
1600 REM ********************
1601 REM * STEP 11  (HLMSRI) *
1602 REM ********************
1610 PRINT
1619 GOTO 1640
1620 PRINT "ENTER OVERALL PANEL THICKNESS (IN.) ";
1630 INPUT T1
1631 PRINT
1632 RETURN
1640 LET N1=8/(T1-Y8)/L2/L1^2*E5/(E1*1.1)
1650 LET N2=8/Y8/L2/L1^2*E5/(E2*1.1)
1660 LET N[9]=F1*N1
1670 LET N[10]=F2*N2
1680 IF N[9] <= N[10] THEN 1695
1685 LET P2=N[10]
1690 GOTO 1696
1695 LET P2=N[9]
1696 PRINT
1700 REM ********************
```


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Table 3 (continued)

```
1701 REM * STEP 12 (HLMSRI) *
1702 REM ***********************
1709 GØTØ 1750
1710 PRINT "ENTER AREA // PLIES ØUTSIDE CRITICAL PLANES,TØP&BØT."
1711 PRINT "   SKINS, RESP'Y (IN.2 / 48 IN.)"
1712 PRINT "   (2ND&6TH CØLS, HLMSRI FIG.4 AND PDS3 TABLE P.14)"
1720 INPUT A6,A7
1721 PRINT
1730 PRINT "ENTER Y-PRIME RELATED VALUES(SAME SØURCE,3RD&7TH CØLS,IN.)"
1740 INPUT Y9,Y0
1741 PRINT
1742 RETURN
1750 LET Q1=A6*(L2/48)*(T1-Y7-Y9)
1760 LET Q2=A7*(L2/48)*(Y7-Y0)
1769 GØTØ 1790
1770 PRINT "ENTER 3 STRINGER WIDTH TØTALS (IN.) IN FØLLØWING ØRDER,"
1771 PRINT "   SEPARATED BY CØMMAS:"
1772 PRINT "      UNGLUED (PRØTRUDING) STRINGER(S) WIDTH (TØTAL IN.),"
1773 PRINT "      GLUELINE (TØTAL IN.) WIDTH ØF EXTERIØR STRINGERS"
1774 PRINT "      WHØSE CLEAR DIST.TØ PANEL EDGE IS LESS THAN HALF"
1775 PRINT "      CLEAR DIST.BETW.STRINGERS,"
1776 PRINT "      GLUELINE (TØTAL IN.) WIDTH ØF ALL ØTHER STRINGERS."
1780 INPUT T2,T3,T4
1781 PRINT
1782 RETURN
1790 IF T5=T2+T3+T4 THEN 1819
1800 PRINT "SUM ØF STRINGER WIDTHS NØT EQUAL TØ 'TØTAL WIDTH ØF"
1801 PRINT "   STRINGERS' ENTERED UNDER STEP 4"
1802 PRINT
1810 GØSUB 1770
1819 GØTØ 1840
1820 PRINT "ENTER F-SUB S FØR TØP,BØT. SKINS, RESP'Y (PSI)"
1821 PRINT "   (PDS,P.17)"
1830 INPUT F3,F4
1831 PRINT
1832 RETURN
1840 LET N[1]=F3*(.5*T3+T4)
1850 LET N[2]=F4*(.5*T3+T4)
1851 REM    N(1) AND N(2) ARE SUMMATIØN F-SUB S TIMES T VALUES
1852 REM      FØR TØP AND BØTTØM SKINS, RESP'Y
1855 LET N[3]=2*N[1]/L1/L2/Q1*E4/(E1*1.1)
1857 LET N[4]=2*N[2]/L1/L2/Q2*E4/(E2*1.1)
1860 IF N[3]>N[4] THEN 1890
1870 LET P3=N[3]
1885 GØTØ 1910
1890 LET P3=N[4]
1900 REM ***********************
1901 REM * STEP 13 (HLMSRI) *
1902 REM ***********************
1910 LET Q4=A3*(1.5*(Y7-2*Y2))/(A3/T5)
1920 LET Q5=A2/12*L2*(Y7-Y2)
1930 LET Q3=Q4+Q5*E2*1.1/(E3*1.03)
1939 GØTØ 1960
1940 PRINT "ENTER ALLØWABLE HØRIZ.SHEAR STRESS IN STRNGRS (PSI)"
1941 PRINT "   (NDS)"
1950 INPUT F5
1951 PRINT
1952 RETURN
1960 LET P4=2*F5*T5/(L1*L2*Q3)*(E4/(E3*1.03))
2000 REM ***********************
2001 REM * STEP 14 (HLMSRI) *
2002 REM ***********************
2009 GØTØ 2050
2010 PRINT "ENTER ALLØWABLE STRESS IN BEARING ØN PLYWØØD BØT.FACE(PSI)"
2011 PRINT "   (PDS,P.17)"
2012 INPUT F6
2013 PRINT
2014 RETURN
2050 LET P5=P2
2060 IF P5 <= P3 THEN 2080
2070 LET P5=P3
2080 IF P5 <= P4 THEN 2094
2090 LET P5=P4
2094 REM
2100 LET L3=L1/(2*(F6/P5-1))
2102 IF L3 >= 1.5 THEN 2106
2104 LET L3=1.5
2105 GØTØ 2110
2106 IF 2*L3-INT(2*L3)>.01 THEN 2109
2107 LET L3=INT(2*L3)/2
2108 GØTØ 2110
2109 LET L3=INT(2*L3+1/2)/2
2110 REM
2140 GØTØ 6000
2200 REM ***********************
2201 REM * STEP 15B (HLMSRI) *
2202 REM ***********************
2210 PRINT "ØBSERVE PRESCRIBED MIN. LENGTHS FØR TENSIØN SPLICE-"
2211 PRINT "   PLATES(PDS,P.26 TABLE) & ØTHER LIMITATIØNS(HLMSRI)"
2212 PRINT
2219 GØTØ 2250
2220 PRINT "ENTER ALLØWABLE SPLICE-PLATE MAX.STRESS (PSI)"
2221 PRINT "   (PDS,P.26 TABLE)"
2225 INPUT F7
2226 PRINT
2227 RETURN
2230 PRINT "ENTER TØTAL LENGTH ØF SPLICE-PLATE ACRØSS PANEL (IN.)"
2231 PRINT "   (HLMSRI,STEP 15B; PDS3,P.4 FIG.)"
2240 INPUT L5
2241 PRINT
2242 RETURN
2250 IF L5<L2 THEN 2280
2260 PRINT "SPLICE-PLATE LENGTH MUST BE SHØRTER THAN PANEL WIDTH"
2261 PRINT
2270 GØSUB 2230
2280 LET P6=8*(F7*L5/L2)/Y7/L2/L1+2*E4/(E2*1.1)
2289 PRINT
2290 PRINT "P-SUB P = ";P6;"   PSI"
2291 PRINT "IF P-SUB P < P-SUB M (";P5;") ØR DESIGN TL, WHICHEVER"
2292 PRINT "   CRITERIØN IS USED, SPLICE-PLATE SHØULD BE REDESIGNED"
2293 PRINT "   ØR RELØCATED (P-SUB P CALC'D ØN MID-SPAN LØCATIØN)"
2294 PRINT
```

Table 3 (concluded)

```
4999  GOTO 6000
5000   FOR I=1 TO 5
5010   PRINT
5020   NEXT I
5030  RETURN
5040  PRINT "ENTER TOP,BOT.SKIN NOM.TH.S,STRINGER NOM.SIZE,"
5041  PRINT "PLYWD TYPE&GRADE,SPECIES GRP"
5042  INPUT B$,C$,D$,E$,N[18]
5043  PRINT
5044  RETURN
6000  PRINT "TOP SKIN ";B$;"   BOT.SKIN ";C$;"   STRINGERS ";D$
6010  PRINT "PLYWOOD: ";E$;"   SPECIES GROUP OF FACE PLY #";N[18]
6020  PRINT "NO. STRINGERS = ";T5/1.5
6022  PRINT "CLEAR SPAN: ";L1
6030  PRINT
6040  PRINT "P-SUB D","P-SUB T","P-SUB BT","P-SUB BB","P-SUB V"
6050  PRINT INT(P1*100+1/2)/100,INT(P7*100+1/2)/100,
6052  PRINT INT(N[9]*100+1/2)/100,INT(N[10]*100+1/2)/100,
6054  PRINT INT(P4*100+1/2)/100
6056  PRINT
6058  PRINT "P-SUB ST","P-SUB SB","L-SUB E","P-SUB M","P-SUB DM"
6059  PRINT INT(N[13]*100+1/2)/100,INT(N[14]*100+1/2)/100,
6060  PRINT L3,
6062  PRINT INT(P5*100+1/2)/100,INT(.75*P5*100+1/2)/100
6064  PRINT
6070  PRINT "STRESSES: F1","F2","F3","F4","F5"
6071  PRINT F1,F2,F3,F4,F5
6072  PRINT
6073  PRINT "STRESS F6","    ","E'S: E1","E2","E3"
6074  PRINT F6,"    ",E1,E2,E3
6075  PRINT
6076  PRINT "Y-BAR (DEFL.)","EI-SUB G","Y-BAR(BEND'G)","EI-SUB N"
6078  PRINT INT(Y7*1000+1/2)/1000,E4,INT(Y8*1000+1/2)/1000,E5
6090  GOSUB 5000
6092  GOTO 9000
9000  LET N[16]=L1
9010  LET N[17]=F5
9012  LET F1=N[19]
9014  LET F2=N[20]
9020  READ L1,F5,E3
9030  IF L1=0 THEN 9900
9040  IF N[16] <> L1 THEN 192
9050  IF N[17] <> F5 THEN 192
9060  GOTO 9020
9100  DATA 24,280,1.E+06
9120  DATA 96,280,1.E+06
9130  DATA 24,380,1.5E+06
9150  DATA 96,380,1.5E+06
9160  DATA 0,0,0
9900  RESTORE
9910  PRINT "INPUT L1,F5,E3"
9920  INPUT L1,F5,E3
9930  STOP
9999  END
```

```
LIS
HMPSP3

0020  REM    THIS CHANGE FOR HMPSP2 PERMITS USE OF DIFFERENT TYPES/
0022  REM    GRADES OF PLYWOOD IN TOP AND BOTTOM SKINS OF PSSP'S:
0024  REM
0120  DIM N[21],A$[10],F$[20]
5040  PRINT "ENTER TOP SKIN NOM.TH.,PLYWOOD TYPE&GRADE,SPECIES GRP"
5042  INPUT B$,E$,N[18]
5043  PRINT
5044  PRINT "ENTER BOT.SKIN NOM.TH.,PLYWOOD TYPE&GRADE,SPECIES GRP"
5046  INPUT C$,F$,N[21]
5047  PRINT
5048  PRINT "ENTER STRINGER NOM. SIZE";
5050  INPUT D$
5051  PRINT
5052  RETURN
6000  PRINT "TOP SKIN: ";B$;" PLYWOOD: ";E$
6001  PRINT "   SPECIES GROUP OF FACE PLY # ";N[18]
6005  PRINT "BOT.SKIN: ";C$;" PLYWOOD: ";F$
6006  PRINT "   SPECIES GROUP OF FACE PLY # ";N[21]
6020  PRINT "STRINGERS: ";T5/1.5;"  ";D$
5041
6010
```


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Figures 5 include graphs of the design results in terms of p_{dm} versus clear span, but only for the 9-stringer panels, and the two plywoods used throughout; also included are correction factors for use of 4, 5 and 7 stringers in lieu of 9 (per 48-inch wide panel) and for use of plywood face species group #3 in lieu of #1 (used in the graphs). Correction Factors of Figure 5A apply only to the 1:1 slope portions of the graphs of Figure 5B (i.e., not to the steeper slope at right ends of some lines in the right side graph).

Figures 6 are in SI units and parallel Figures 5.

As noted in Figures 5A and 6A, the pre-designs of Table 2 (used for Figures 5 and 6) are limited to two plywoods: Underlayment Interior (APA) in face ply group species #1 and #3, for 1/2" (13 mm), 5/8" (16 mm) and 3/4" (19 mm) thicknesses; and, 2.4.1 Interior (APA), which is only made in #1,* for the 1-1/8" (29 mm) thickness. These plywoods have high availability in local lumberyards in the indicated thicknesses.

Also having similar availability are three other plywoods: Underlayment Exterior (APA), C-D Interior and C-C Exterior. Pre-designs were, therefore, prepared using these three plywoods, in each case with the same plywood (and face ply group species, using #1 and #3 in turn) for both top and bottom skins, for panels having 4 and 9 stringers per 48-inch (1.219 m) width; designs are comparable to Curve Nos. 3 and 16 of Figures 5 and 6 in the case of the 9-stringer panels, the pre-designs comparable to the No. 16 curves all making use of the same 1-1/8" (29 mm) top skin of 2.4.1 Interior (group species #1) as before. The 96 pre-designs covering these panels show the following results compared to the pre-designs of Figures 5 and 6: Ratios of p_{dm} values found to those of the earlier pre-designs were 1.00 to 1.01 for all designs comparable to the No. 16 curves, and for all designs comparable to the No. 3 curves except only for those panels using 4 higher strength stringers per panel. In the latter case, p_{dm} ratios found were from 1.03 to 1.09 times those of the earlier pre-designs. For applied uses, it is recommended that the three additional plywoods be treated as full alternates (to the Underlayment Interior (APA) plywood) in using Figures 5 and 6, without

* Actually in Groups 1-3 but with different manufacturing guides so adjusted that all 3 have same strength characteristics as Species Group 1 Face Plies.

The graphs of Figure 5B show data from Table 2, specifically that for 48-inch wide plywood stressed-skin panels having 9 stringers of two different horizontal shear (and modulus of elasticity) strengths. The graph lines each have a Curve No. assigned, in order to provide basic information on stringer nominal sizes and plywood thicknesses used in design. Only Underlayment Interior (APA) plywood was used for 1/2, 5/8 and 3/4-inch plywood; 2.4.1 Interior (APA) was used for the 1-1/8-inch plywood. Face Ply Group Species #1 and #3 were used for the designs (same group for both top and bottom skins), except where the 1-1/8-inch was used alone (only #1 is available);§ where the latter was used as the top skin and a thinner bottom skin was used, bottom skins of both #1 and #3 were used in designs. Certain Basic Data and Correction Factors follow:

BASIC DATA				CORRECTION FACTORS									
				Face Species Grp 3 for 1*				Stringers Fewer Than 9					
				Lower Str. Stringers		Higher Str. Stringers		Lower Str. Stringers			Higher Str. Stringers		
Curve No.	Top Skin	Bot. Skin	Stringers (nominal)	4	9	4	9	4	5†	7	4	5†	7
1	1/2	1/2	2x4	.93	.90	.92	.90	.53		.82	.54		.83
2	5/8	1/2	"	"	"	.91	"	"	.63	"	"	.64	"
3	3/4	1/2	"	"	"	1.06	"	"		"	.44/.52‡		"
4	3/4	3/4	"	.94	.91	.94	.91	"		"	.52		"
5	1-1/8	1/2	"	"	.98	"	.97	.44		"	.36		.75
6	"	3/4	"	"	.97	"	"	.45		"	.37		.77
7	"	1-1/8	"					.47		.81	.39		.82
8	1/2	1/2	2x6	.95	.94	.95	.94	.49		"	.50		.81
9	5/8	1/2	"	"	"	.94	"	"		"	"		"
10	3/4	1/2	"	.96	"	1.06	"	"		"	.41/.50‡		"
11	3/4	3/4	"	.95	"	1.02	"	"		"	.48		"
12	1-1/8	1/2	"	.94	1.01	.94	1.01	.41		.80	.35		.79
13	"	3/4	"	"	"	"	"	.43		"	.36		.80
14	"	1-1/8	"					.48		"	.41		.81
15	1-1/8	1/2	2x8	.94	1.04	.95	1.03	.39	.53	.79	.32	.46	.80/.74‡
16	"	3/4	"	"	"	.94	"	.41	.56	"	.34	.48	.78
17	"	1-1/8	"					.47	.58	"	.40	.56	.79

All have face ply species group No. 1 (unless stated otherwise); stringers are of two strengths: low, with F_v=280 and E=1,000,000 for 2x4's, 1,100,000 for others; high, with 380, 1,500,000 and 1,800,000, respectively (all psi).

* Except for 1-1/8 skins (only available in #1).§ Interpolate for 5 and 7 stringers by taking 20% and 60%, respectively of the difference from 4 to 9.

† If no 5 value, use 1/3 of difference from 4 to 7.

‡ Species Grp. #1 and #3 values, respectively.

1 kPa (kilo pascal) = 1 cb (centibar) = 1 kN/m^2 = 0.010197 kg/cm^2 = 0.145038 psi.

All stringers run parallel to the plywood face grain.

§ See footnote * on page A1-31

FIGURE 5A PSSP DESIGNS FOR LOWER AND HIGHER STRENGTH STRINGERS, 9 PER 48-INCH PANEL

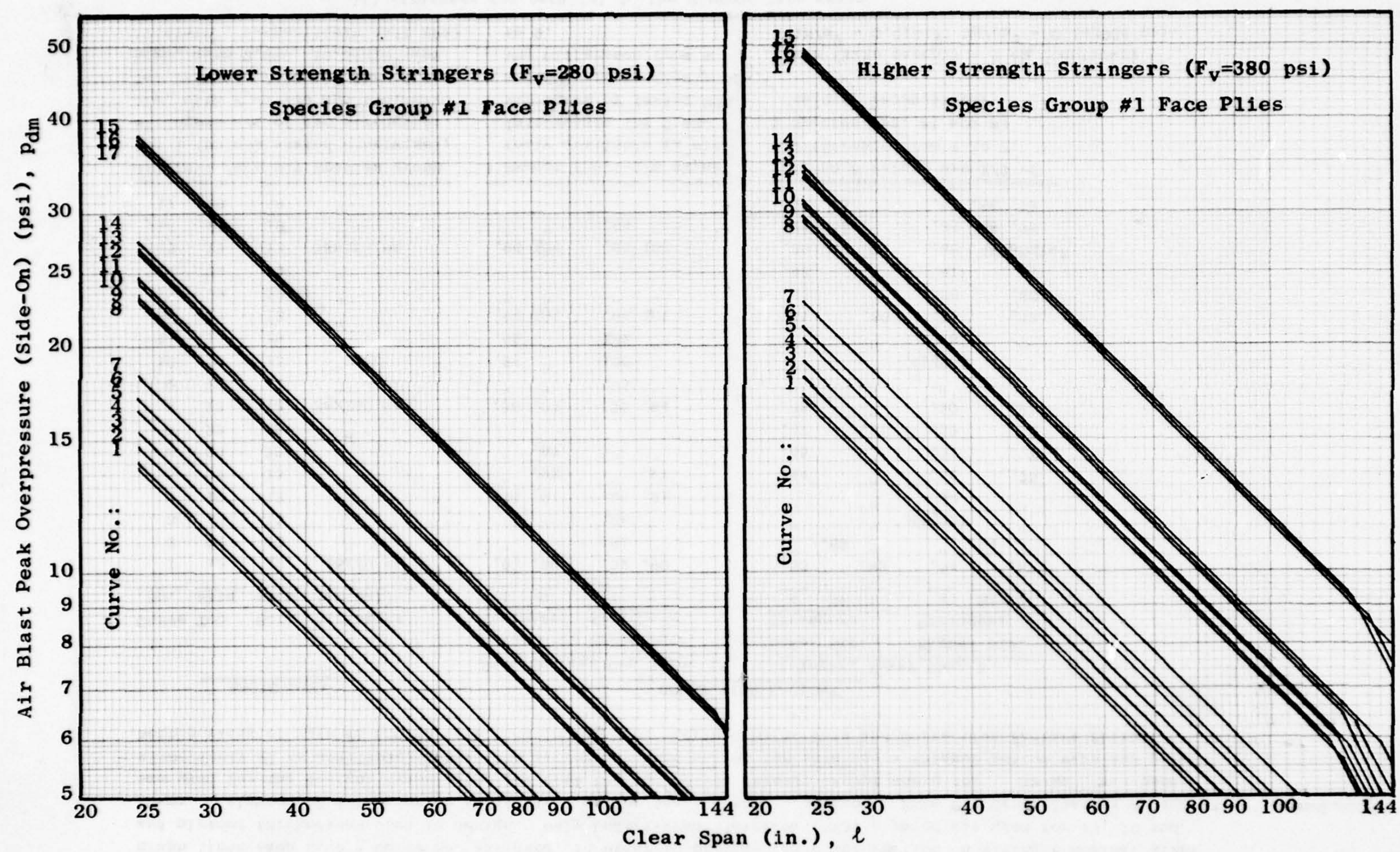

FIGURE 5B PSSP DESIGNS FOR LOWER AND HIGHER STRENGTH STRINGERS, 9 PER 48-INCH PANEL

The graphs of Figure 5B show data from Table 2, specifically that for 1.219-m wide plywood stressed-skin panels having 9 stringers of two different horizontal shear (and modulus of elasticity) strengths. The graph lines each have a *Curve No. assigned, in order to provide* basic information on stringer nominal sizes and plywood thicknesses used in design. Only Underlayment Interior (APA) plywood was used for 13, 16 and 19-mm plywood; 2.4.1 Interior (APA) was used for the 29-mm plywood. Face Ply Group Species #1 and #3 were used for the designs (same group for both top and bottom skins), except where the 29-mm was used alone (only #1 is available):§ where the latter was used as the top skin and a thinner bottom skin was used, bottom skins of both #1 and #3 were used in designs. Certain Basic Data and Correction Factors follow:

BASIC DATA				CORRECTION FACTORS									
				Face Species Grp 3 for 1*				Stringers Fewer Than 9					
				Lower Str. Stringers		Higher Str. Stringers		Lower Str. Stringers			Higher Str. Stringers		
Curve No.	Top Skin	Bot. Skin	Stringers (actual)	4	9	4	9	4	5†	7	4	5†	7
1	13	13	38x89 mm	.93	.90	.92	.90	.53		.82	.54		.83
2	16	13	"	"	"	.91	"	"	.63	"	"	.64	"
3	19	13	"	"	"	1.06	"	"		"	.44/52‡		"
4	19	19	"	.94	.91	.94	.91	"		"	.52		"
5	29	13	"	"	.98	"	.97	.44		"	.36		.75
6	29	19	"	"	.97	"	"	.45		"	.37		.77
7	29	29	"					.47		.81	.39		.82
8	13	13	38x140 mm	.95	.94	.95	.94	.49		"	.50		.81
9	16	13	"	"	"	.94	"	"		"	"		"
10	19	13	"	.96	"	1.06	"	"		"	.41/50‡		"
11	19	19	"	.95	"	1.02	"	"		"	.48		"
12	29	13	"	.94	1.01	.94	1.01	.41		.80	.35		.79
13	29	19	"	"	"	"	"	.43		"	.36		.80
14	29	29	"					.48		"	.41		.81
15	29	13	38x184 mm	.94	1.04	.95	1.03	.39	.53	.79	.32	.46	.80/.74‡
16	29	19	"	"	"	.94	"	.41	.56	"	.34	.48	.78
17	29	29	"					.47	.58	"	.40	.56	.79

All have face ply species group No. 1 (unless stated otherwise); stringers are of two strengths: low, with F_v=1,930 and E=6.89x10^6 for 38x89's, 7.58x10^6 for others; high, with 2,620, 10.34x10^6 and 12.41x10^6, respectively (all kPa).

* Except for 1-1/8 skins (only available in #1).§ Interpolate for 5 and 7 stringers by taking 20% and 60%, respectively of the difference from 4 to 9.

† If no 5 value, use 1/3 of difference from 4 to 7.

‡ Species Grp. #1 and #3 values, respectively.

1 kPa (kilo pascal) = 1 cb (centibar) = 1 kN/m^2 = 0.010197 kg/cm^2 = 0.145038 psi.

All stringers run parallel to the plywood face grain.

§ See footnote * on page A1-31

FIGURE 6A PSSP DESIGNS FOR LOWER AND HIGHER STRENGTH STRINGERS, 9 PER 1.219-METER PANEL

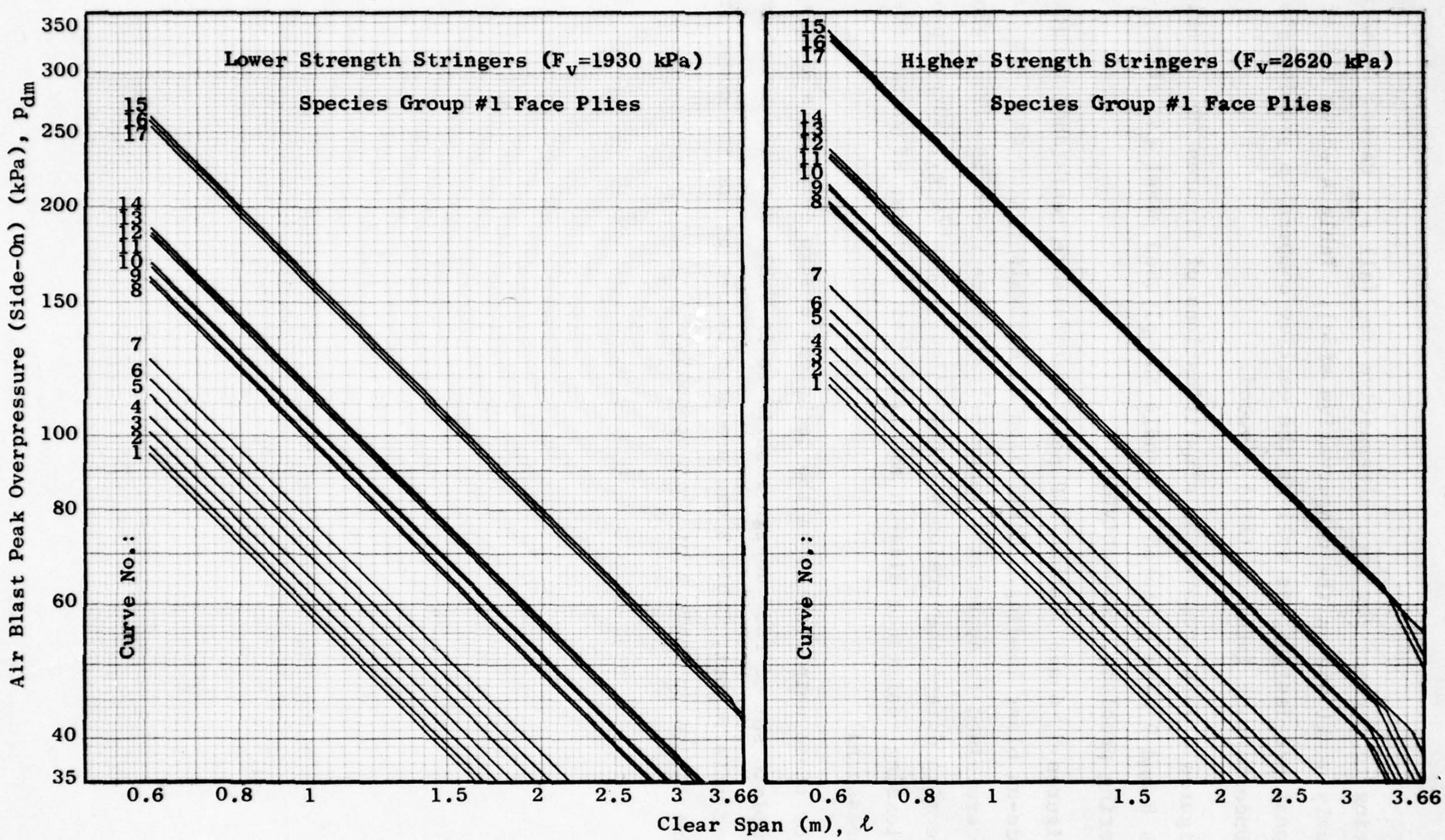

FIGURE 6B PSSP DESIGNS FOR LOWER AND HIGHER STRENGTH STRINGERS, 9 PER 1.219-METER PANEL

attempting to correct for such alternative use (all p_{dm} ratios found were relatively small and on the conservative side). Table 4 shows all of the additional pre-designs, as well as the earlier comparable pre-designs using Underlayment Interior (APA) plywood.

Figures 7 were prepared as simplifications of Figures 5B and 6B. Figures 8 and 9 were prepared to handle the plywood panel and stringers end-bearing problems, respectively.

Figures 5, 6 and 7 show PSSP peak overpressure resistance capacity for side-on blast loading. Conversion to equivalent head-on blast loading is explained in Appendix B (page 6-117) where there is also a graph that permits direct conversion without calculations (e.g., 30 psi peak blast loading resistance side-on equals 14 psi head-on; SI values are also presented).

For those uninterested in the technical design details, a simpler yet complete set of PSSP design results is in Table 2 of the front (main body) of this report; Table 2 was produced by use of the two computer programs listed in Table 5 of this appendix.

Table 4 PSSP DESIGNS WITH THREE OTHER PLYWOODS

P_{dm} Vs. Clear Span — STRINGERS: As shown (nominal) — Panel width: 48"

PLYWOOD top/bot.skin	Low Strength (F_v/E) 280/1000000(2x4) or 1100000(2x8) 24" 4	24" 9	96" 4	96" 9	144" 4	144" 9 stringers		High Strength (F_v/E) 380/1500000 or 1800000 24" 4	24" 9	96" 4	96" 9	144" 4	144" 9
3/4 & 1/2 #1	7.63st&v		1.91st&v				2x4's	7.92st		1.98st			
Underlay.-		14.72v		3.68v					18.08v		4.52v		
Interior#3	7.13v		1.78v					8.38st		2.09st			
		13.32v		3.16bt					16.21v		3.55bt		
Underlay.-#1	7.63v		1.91v					8.39st		2.10st			
Exterior		14.72v		3.68v					18.08v		4.52v		
#3	7.13v		1.78v					8.88v		2.22v			
		13.32v		3.16bt					16.21v		3.55bt		
C-D #1	7.63v		1.91v					8.16st		2.04st			
Interior		14.71v		3.68v					18.06v		4.51v		
#3	7.12v		1.78v					8.60st		2.15st			
		13.30v		3.18bt					16.19v		3.56v		
C-C #1	7.63v		1.91v					8.65st		2.16st			
Exterior		14.71v		3.68v					18.06v		4.51v		
#3	7.12v		1.78v					8.87v		2.22v			
		13.30v		3.33v					16.19v		3.81bt		
1-1/8 & 3/4 #1	16.89st				2.81st		2x8's	18.42st				3.07st	
2.4.1 Int.		39.20v				6.53v			51.13v				8.01bt
& Undrl.- #1 &	15.90st				2.65st			17.33st				2.89st	
Interior#3		40.70v				6.32bt			52.67v				7.58bt
2.4.1 Int.#1	16.89st				2.81st			18.42st				3.07st	
& Undrl.-		39.20v				6.53v			51.13v				8.01bt
Exterior#1 &	15.90st				2.65st			17.33st				2.89st	
#3		40.70v				6.32bt			52.67v				7.58bt
2.4.1 Int.#1	16.97st				2.83st			18.52st				3.09st	
& C-D		39.09v				6.52v			51.01v				8.05bt
Interior#1 &	15.97st				2.66st			17.41st				2.90st	
#3		40.59v				6.35bt			52.55v				7.61bt
2.4.1 Int.#1	16.97st				2.83st			18.52st				3.09st	
& C-C		39.09v				6.52v			51.01v				8.05bt
Exterior#1 &	15.97st				2.66st			17.41st				2.90st	
#3		40.59v				6.35bt			52.55v				7.61bt

* Data for panels with Underlayment Interior (APA) plywood taken from Table 2. See Table 2 for meaning of lower case letters following P_{dm} values.

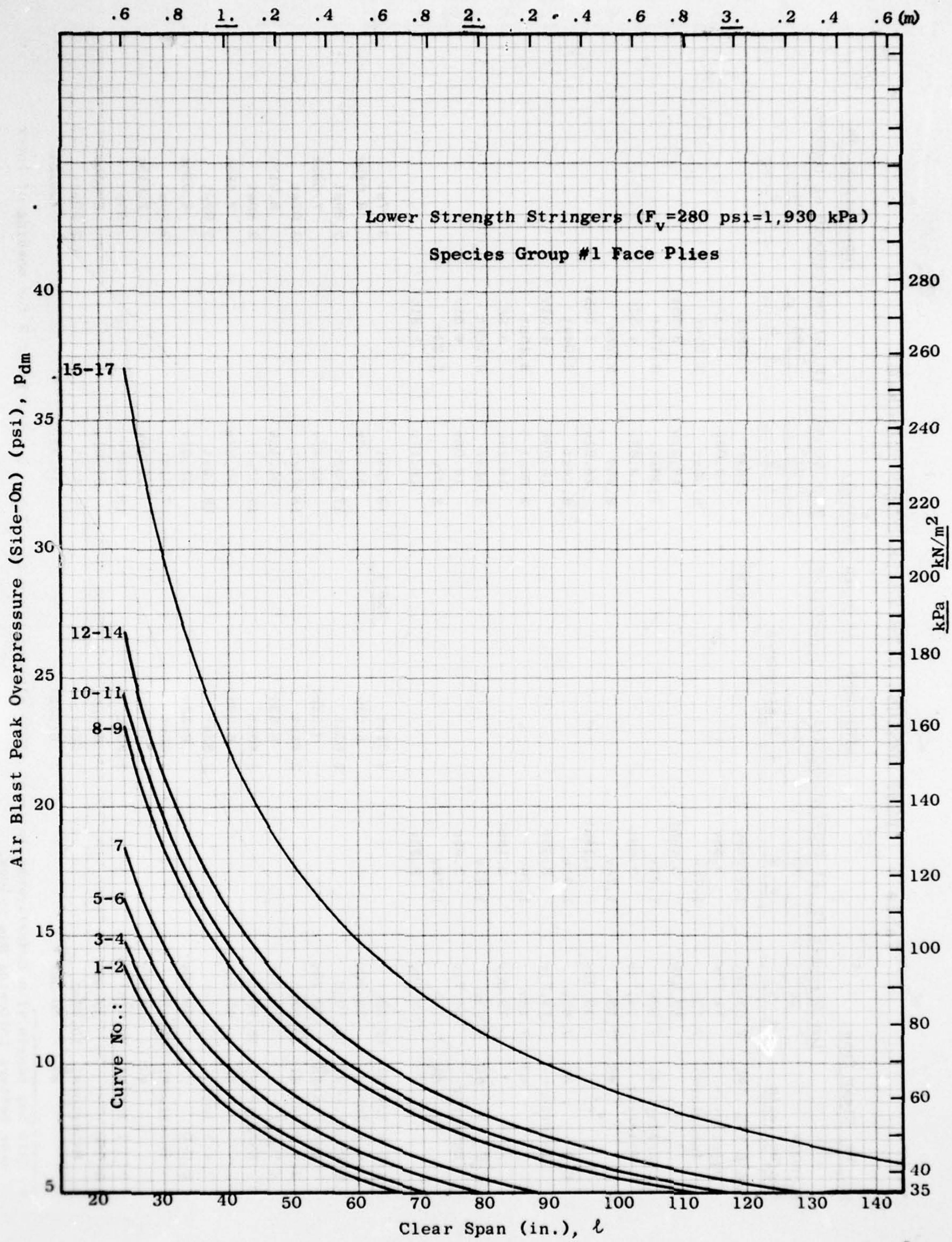

FIGURE 7A PSSP DESIGNS FOR LOWER STRENGTH STRINGERS, 9 PER 48-INCH (1.219-METER) PANEL

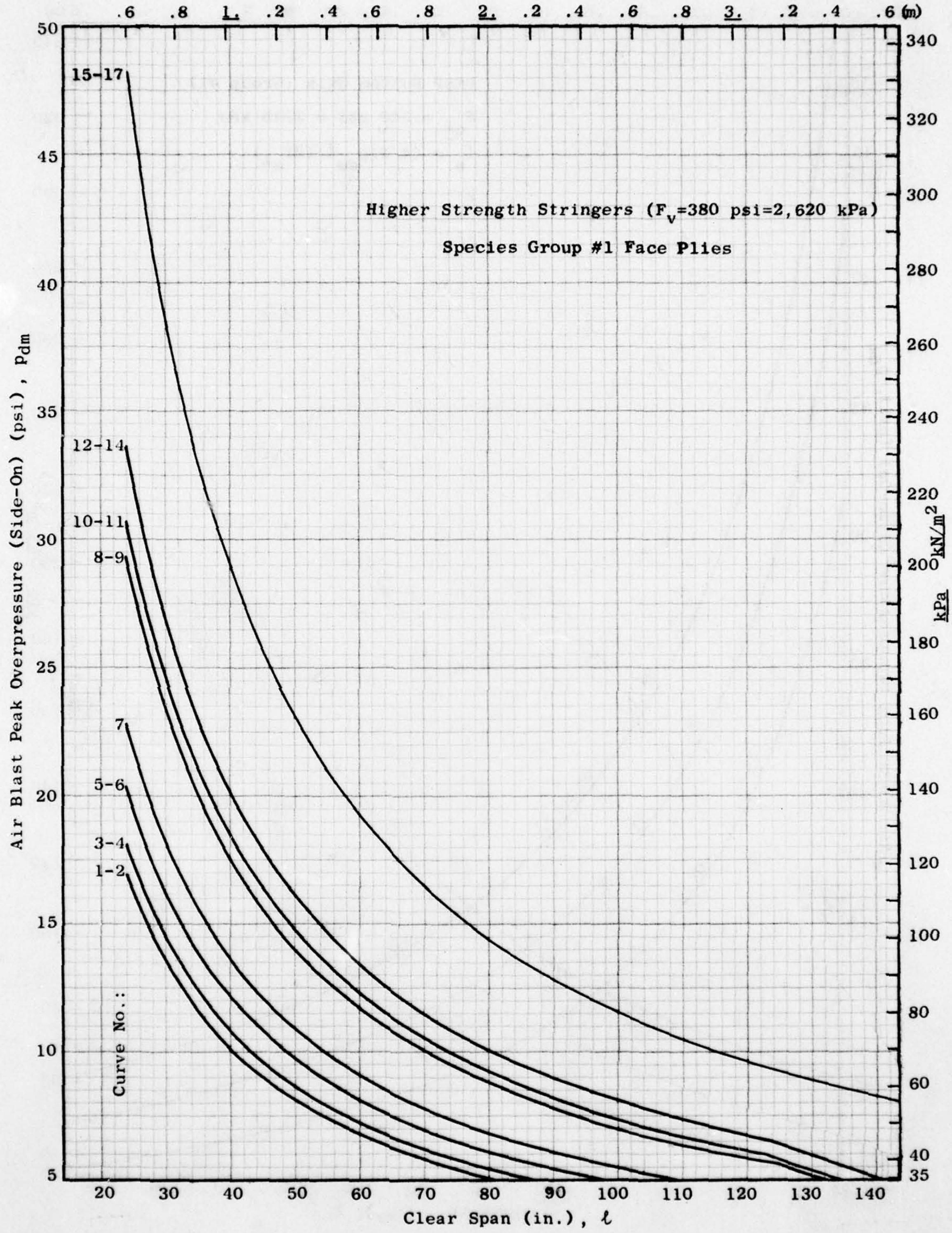

FIGURE 7B PSSP DESIGNS FOR HIGHER STRENGTH STRINGERS, 9 PER 48-INCH (1.219-METER) PANEL

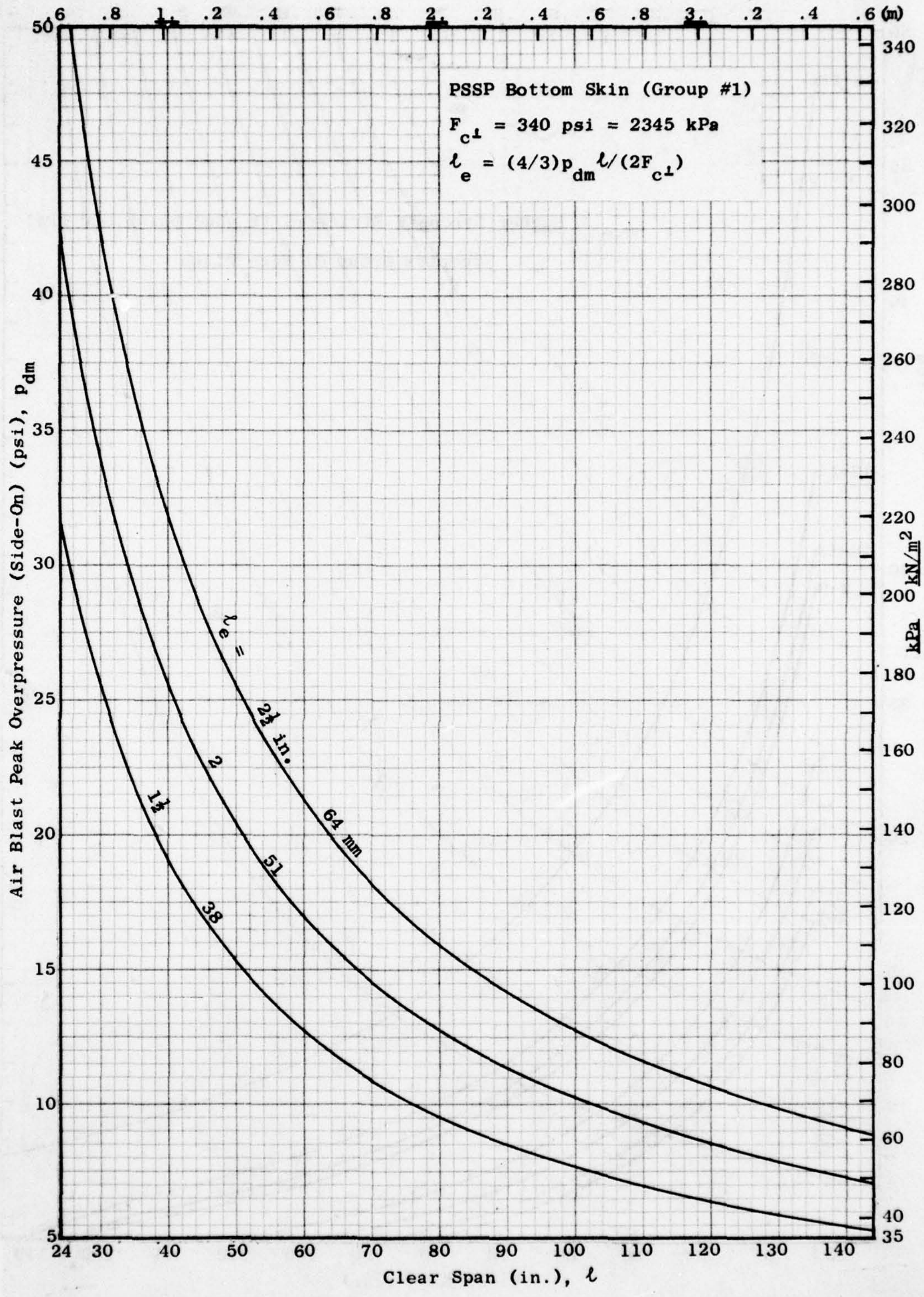

FIGURE 8A PSSP DESIGNS - REQUIRED PLYWOOD END BEARING AT EACH END (Face Ply Species Group #1)

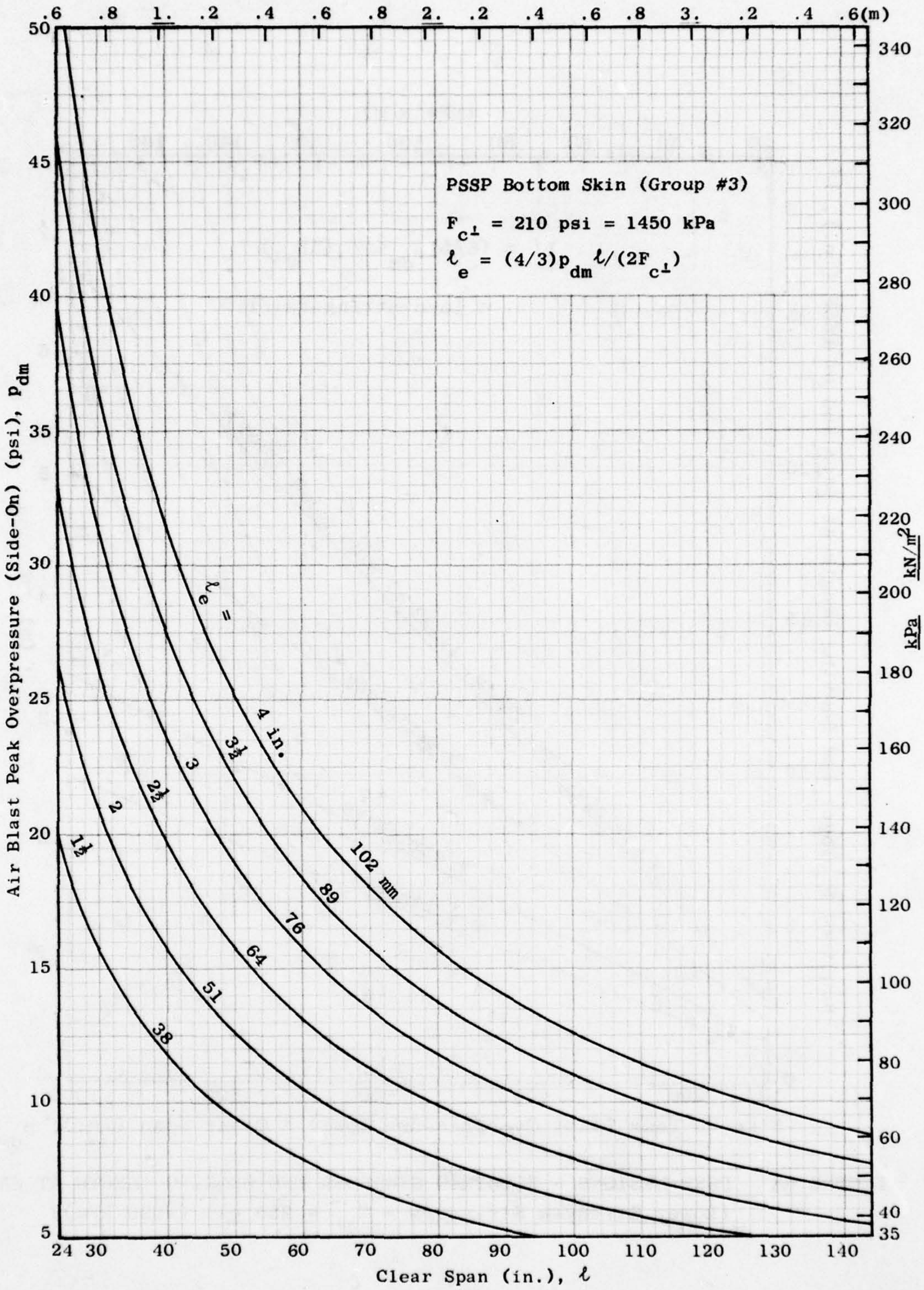

FIGURE 8B PSSP DESIGNS - REQUIRED PLYWOOD END BEARING AT EACH END (Face Ply Species Group #3)

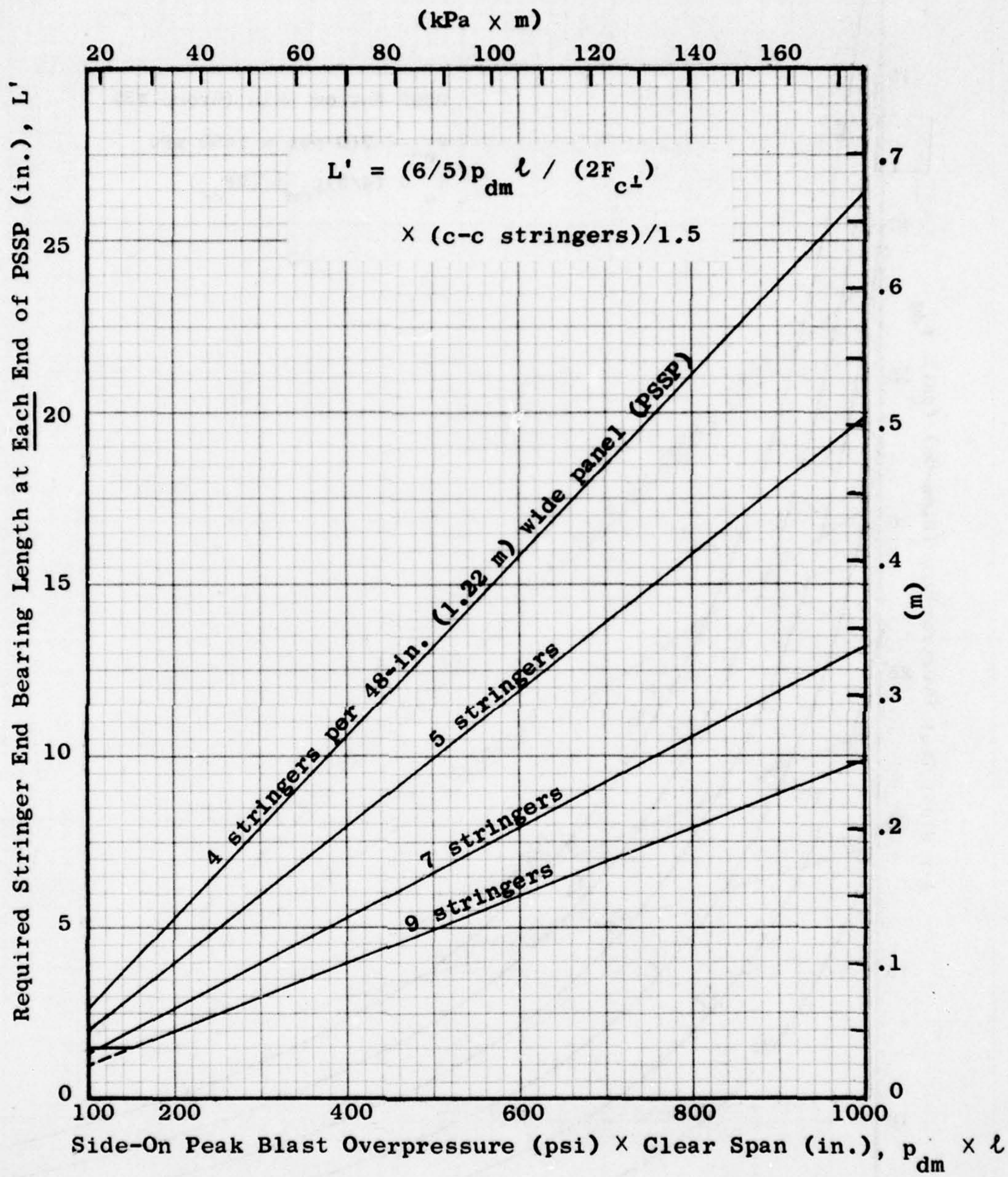

FIGURE 9A PSSP DESIGNS - REQUIRED STRINGER END BEARING LENGTH AT EACH END (Lower Strength Stringers - $F_{c\perp}$ = 235 psi (1620 kPa))

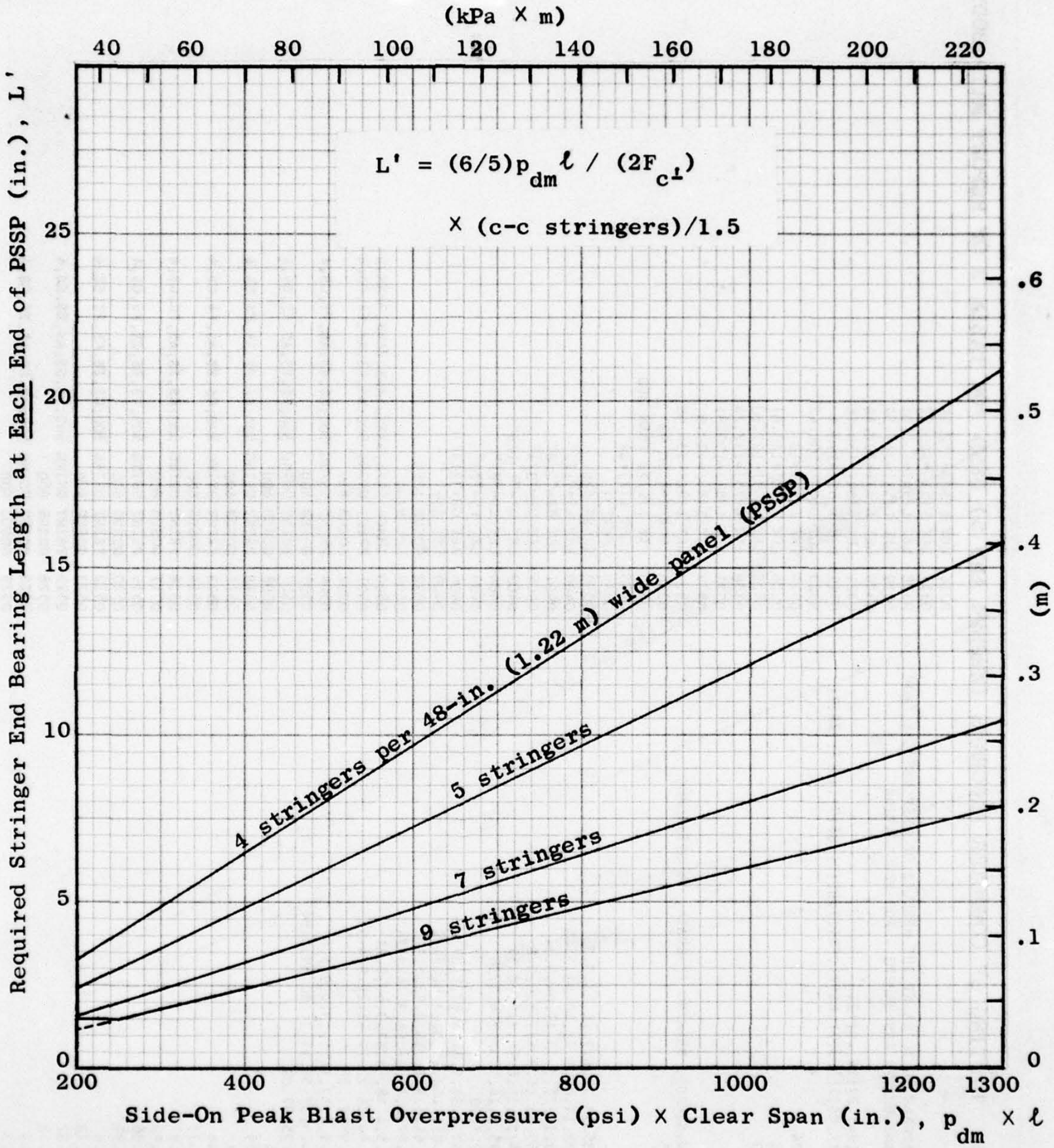

FIGURE 9B PSSP DESIGNS - REQUIRED STRINGER END BEARING LENGTH AT EACH END (Higher Strength Stringers - $F_{c\perp}$ = 385 psi (2655 kPa))

Table 5 LISTING OF COMPUTER PROGRAMS (HMPSP4 AND 5) USED FOR TABLE 2 OF REPORT MAIN BODY

HMPSP4

```
0050 REM    THIS PROGRAM IS TO PRINT OUT RESULTS OF PSSP DESIGNS FROM
0052 REM     PROGRAMS HMPSP2 AND HMPSP3 - FOR PUBLICATION
0054 REM
0100 DIM L[124],M[124],P[124],Q[124]
0110 DIM A$[7],B$[7],C$[7],D$[7],E$[7],F$[7],G$[7],H$[7],I$[7],Z$[7]
0120 DIM B[124,2]
0130  FOR I=1 TO 124
0132   FOR J=1 TO 2
0134   LET B[I,J]=0
0136   NEXT J
0138  NEXT I
0154 LET F8=235
0155 REM    F8=ALLOW.STRESS, BEARING // GRAIN, IN STRINGERS
0200  FOR I=1 TO 93
0210  READ P[I]
0220  LET L[I]=0
0230  NEXT I
0250 DATA 7.21,11.35,13.79,6.7,10.33,3.26
0252 DATA 7.36,11.58,14.06,6.83,10.53,3.45
0254 DATA 7.63,12.1,14.72,7.13,11.04,3.51
0256 DATA 7.97,12.69,15.46,7.47,11.6,3.6
0258 DATA 7.36,13.43,3.11,6.94,2.41,3.32
0260 DATA 7.81,13.95,3.14,7.37,2.4,3.36
0262 DATA 8.58,14.9,3.18
0264 DATA 11.4,18.63,4.31,1.84,3.67,5.07
0266 DATA 11.55,18.87,4.48,11.01,3.81,5.29
0268 DATA 11.98,19.64,4.5,11.45,3.85,5.37
0270 DATA 12.13,19.87,4.35,11.58,3.74,5.24
0272 DATA 11.54,21.5,4.68,10.87,3.66,5.11
0274 DATA 12.13,21.64,26.92,11.42,21.9,4.93
0276 DATA 13.16,21.98,27.36
0278 DATA 15.55,30.1,6.52,14.67,31.29,7.4
0280 DATA 16.27,29.76,37.56,15.31,30.89,6.96
0282 DATA 17.36,29.35,37.03
0300 LET L[6]=91.84
0301 LET L[12]=88.29
0302 LET L[18]=91.1
0303 LET L[24]=93.46
0304 LET L[27]=126.73
0305 LET L[29]=130.95
0306 LET L[30]=115.96
0307 LET L[33]=130.86
0308 LET L[35]=135.95
0309 LET L[36]=118.6
0310 LET L[39]=138.18
0311 LET L[42]=128.82
0312 LET L[43]=141.48
0313 LET L[44]=115.3
0314 LET L[45]=103.3
0315 LET L[48]=125.43
0316 LET L[50]=112.06
0317 LET L[51]=100.22
0318 LET L[54]=130.01
0319 LET L[56]=115.57
0320 LET L[57]=102.44
0321 LET L[60]=136.18
0322 LET L[62]=120.6
0323 LET L[63]=106.42
0324 LET L[66]=137
0326 LET L[68]=143.01
0328 LET L[69]=127.03
0330 LET L[75]=132.24
0331 LET L[81]=139.91
0332 LET L[84]=127.6
0333 LET L[90]=134.03
0350  FOR I=1 TO 93
0360  IF L[I]>0 THEN 380
0370  LET L[I]=24
0380  NEXT I
0390 GOSUB 620
0400 LET A$="1/2"
0401 LET B$="5/8"
0402 LET C$="3/4"
0403 LET D$="1-1/8"
0404 LET E$="#1"
0405 LET F$="#3"
0406 LET G$="2X4"
0409 LET Z$=" "
0498 GOSUB 1250
0499 LET N1=0
0500 IMAGE 5AXX,2AXX,5AXX,2AXX,3AXX,D
0501 PRINT USING 500;A$,E$,A$,E$,G$,4
0502 GOSUB 600
0504 PRINT USING 500;A$,F$,A$,F$,G$,4
0505 GOSUB 600
0507 PRINT USING 500;B$,E$,A$,E$,G$,4
0508 GOSUB 600
0510 PRINT USING 500;B$,F$,A$,F$,G$,4
0511 GOSUB 600
0513 PRINT USING 500;C$,E$,A$,E$,G$,4
0514 GOSUB 600
0516 PRINT USING 500;C$,F$,A$,F$,G$,4
0517 GOSUB 600
0519 PRINT USING 500;C$,E$,C$,E$,G$,4
0520 GOSUB 600
0522 PRINT USING 500;C$,F$,C$,F$,G$,4
0523 GOSUB 600
0525 PRINT USING 500;D$,E$,A$,E$,G$,4
0526 GOSUB 600
0528 PRINT USING 500;D$,E$,A$,F$,G$,4
0529 GOSUB 600
0531 PRINT USING 500;D$,E$,C$,E$,G$,4
```

Table 5 (continued)

```
0532 GOSUB 600
0534 PRINT USING 500;D$,E$,C$,F$,G$,4
0535 GOSUB 600
0537 PRINT USING 500;D$,E$,D$,E$,G$,4
0538 GOSUB 600
0550 LET N1=N1+1
0552 IF N1>1.5 THEN 580
0554 LET G$="2X6"
0556 GOTO 501
0580 IF N1>2.5 THEN 599
0582 LET G$="2X8"
0584 GOTO 525
0586 GOSUB 1250
0599 GOTO 700
0600 PRINT USING 500;Z$,Z$,Z$,Z$,Z$,5
0601 PRINT USING 500;Z$,Z$,Z$,Z$,Z$,7
0603 PRINT USING 500;Z$,Z$,Z$,Z$,Z$,9
0605 RETURN
0610 LET B[I,1]=(2/3)*Q[I]*M[I]/340
0615 RETURN
0620  FOR I=1 TO 93
0622  LET M[I]=L[I]
0624  LET Q[I]=P[I]
0626  LET L[I]=P[I]=0
0628  NEXT I
0630 LET A=1
0631 LET B=24
0632 LET C=96
0634  FOR I=A TO B
0636  IF M[I]>25 THEN 644
0638  LET L[I]=C
0640  LET P[I]=INT(Q[I]*M[I]/L[I]*100+1/2)/100
0642  GOTO 648
0644  LET L[I]=M[I]
0646  LET P[I]=Q[I]
0648  IF I=93 THEN 660
0650  NEXT I
0652 LET A=25
0653 LET B=93
0654 LET C=144
0656 GOTO 634
0660  FOR I=1 TO 124
0661  LET M[I]=Q[I]=0
0662  NEXT I
0668 LET N=0
0670  FOR I=1 TO 91 STEP 3
0672  LET Q[I+N]=P[I]
0674  LET M[I+N]=L[I]
0675  LET N=N+1
0676  NEXT I
0678 LET N=0
0680  FOR I=2 TO 92 STEP 3
0682  LET N=N+1
0684  LET Q[I+N]=P[I]
0686  LET M[I+N]=L[I]
0690  NEXT I
0695 GOTO 1200
0700 REM    REQD PLYWOOD BEARING LENGTH AT EACH END: #1 AND #3 FACE PLY SP.GR.
0710  FOR I=1 TO 49 STEP 8
0720  GOSUB 610
0730  NEXT I
0740  FOR I=2 TO 50 STEP 8
0750  GOSUB 610
0760  NEXT I
0770  FOR I=3 TO 51 STEP 8
0780  GOSUB 610
0790  NEXT I
0792  FOR I=4 TO 52 STEP 8
0794  GOSUB 610
0796  NEXT I
0800  FOR I=53 TO 101 STEP 8
0810  GOSUB 610
0820  NEXT I
0830  FOR I=54 TO 102 STEP 8
0840  GOSUB 610
0850  NEXT I
0860  FOR I=55 TO 103 STEP 8
0870  GOSUB 610
0880  NEXT I
0882  FOR I=56 TO 104 STEP 8
0884  GOSUB 610
0886  NEXT I
0890  FOR I=105 TO 121 STEP 8
0900  GOSUB 610
0910  NEXT I
0920  FOR I=106 TO 122 STEP 8
0930  GOSUB 610
0940  NEXT I
0950  FOR I=107 TO 123 STEP 8
0960  GOSUB 610
0970  NEXT I
0972  FOR I=108 TO 124 STEP 8
0974  GOSUB 610
0976  NEXT I
0980  FOR I=1 TO 124
0990  IF B[I,1]>0 THEN 1010
1000  LET B[I,1]=(2/3)*Q[I]*M[I]/210
1010  NEXT I
1012  FOR I=1 TO 124
1014  IF B[I,1] >= 1.5 THEN 1018
1016  LET B[I,1]=1.5
1018  NEXT I
1100 REM   REQD BEARING EACH END IN STRINGERS: 4,5,7&9 PER 48-IN.PANEL
1120  FOR I=1 TO 121 STEP 4
```


45

Table 5 (continued)

```
1122  LET B[I,2]=.4/F8*Q[I]*M[I]*15.5
1124  NEXT I
1130  FOR I=2 TO 122 STEP 4
1132  LET B[I,2]=.4/F8*Q[I]*M[I]*11.625
1134  NEXT I
1140  FOR I=3 TO 123 STEP 4
1142  LET B[I,2]=.4/F8*Q[I]*M[I]*7.75
1144  NEXT I
1150  FOR I=4 TO 124 STEP 4
1152  LET B[I,2]=.4/F8*Q[I]*M[I]*5.8125
1154  NEXT I
1199 GOTO 1300
1200 REM   SUBROUTINE STARTING LINE 620 CONTINUED
1210 LET N=0
1212  FOR I=3 TO 93 STEP 3
1214  LET N=N+1
1216  LET Q[I+N]=P[I]
1218  LET M[I+N]=L[I]
1220  NEXT I
1230  FOR I=2 TO 122 STEP 4
1232  LET N1=Q[I+1]-Q[I-1]
1234  LET Q[I]=Q[I-1]+N1/3
1236  LET N2=M[I+1]-M[I-1]
1238  LET M[I]=M[I-1]+N2/3
1240  NEXT I
1242 RETURN
1250  FOR I=1 TO 10
1252  PRINT
1254  NEXT I
1256 RETURN
1260 PRINT USING "#,DDDXX";I
1262 PRINT USING "#,D.DXX";B[I,1]
1263 PRINT USING "#,DD.DXX";B[I,2]
1264 RETURN
1270  FOR L=A TO B STEP C
1274  IF L>M[I] THEN 1280
1276  LET P=INT(Q[I]*M[I]/L+1/2)
1278  GOTO 1282
1280  LET P=INT(Q[I]*M[I]^2/L^2+1/2)
1282  IF P<G THEN 1293
1284  IF L=B THEN 1290
1286  PRINT USING "#,DDXX";P
1288  GOTO 1296
1290  PRINT USING "DDXX";P
1292  GOTO 1298
1293  PRINT USING "4X"
1294  GOTO 1298
1296  NEXT L
1298 RETURN
1300 REM   PEAK (SIDE-ON) OVERPR.VS.SPAN - AND OUTPUT SECTION
1301 GOSUB 1250
1302  FOR I=1 TO 124
1303  LET B[I,1]=INT(B[I,1]*2+.8)/2
1304  LET B[I,2]=INT(B[I,2]*2+.8)/2
1305  NEXT I
1306 LET A=24
1307 LET C=6
1308 LET G=5
1310  FOR I=1 TO 32
1311  LET B=96
1315  GOSUB 1260
1320  GOSUB 1270
1380  NEXT I
1400  FOR I=33 TO 124
1403  LET B=144
1405  GOSUB 1260
1410  GOSUB 1270
1480  NEXT I
1700 GOSUB 1250
9990 STOP
9999 END
```

Table 5 (concluded)

HMPSP5

```
0055 REM    HMPSP4 IS FOR LOWER STRENGTH STRINGERS.  THIS LIST CHANGES HMPSP4
0056 REM    TO HMPSP5, FOR HIGHER STRENGTH STRINGERS.
0057 REM
0154 LET F8=385
0250 DATA 9.09,14.02,16.91,8.32,3.19,4.22
0252 DATA 9.27,14.29,17.23,8.48,3.38,4.47
0254 DATA 7.92,14.98,18.08,8.38,3.46,4.63
0256 DATA 8.47,15.75,19.02,8.98,3.56,4.76
0258 DATA 7.47,2.77,4.52,7.02,2.64,4.57
0260 DATA 7.96,2.93,4.56,7.46,2.83,4.61
0262 DATA 8.81,3.24,4.67
0264 DATA 14.58,4.09,5.62,2.54,4.7,6.32
0266 DATA 14.77,4.25,5.85,2.4,4.89,6.59
0268 DATA 13.65,4.31,5.98,14.52,5.02,6.78
0270 DATA 14.42,25.14,5.83,14.7,4.9,6.66
0272 DATA 12.21,4.58,6.47,11.5,4.4,6.93
0274 DATA 12.85,27.43,6.25,12.05,4.57,6.73
0276 DATA 14.03,27.9,5.91
0278 DATA 16.91,39.24,9.21,15.99,37.64,10.17
0280 DATA 17.69,38.84,8.69,16.63,38.92,9.69
0282 DATA 19.14,38.32,48.19
0300 LET L[5]=95.16
0301 LET L[6]=86.4
0302 LET L[11]=91.37
0303 LET L[12]=82.96
0304 LET L[17]=93.58
0305 LET L[18]=84.1
0306 LET L[23]=95.73
0307 LET L[24]=85.86
0308 LET L[26]=135.35
0309 LET L[27]=108
0310 LET L[29]=133.6
0311 LET L[30]=103.73
0312 LET L[32]=136.75
0313 LET L[33]=111.42
0314 LET L[35]=132.15
0315 LET L[36]=106.42
0316 LET L[38]=138.2
0317 LET L[39]=117.15
0318 LET L[41]=138.39
0319 LET L[42]=124.9
0320 LET L[43]=130.32
0321 LET L[44]=113.73
0322 LET L[45]=104.99
0323 LET L[47]=134.65
0324 LET L[48]=121.3
0325 LET L[49]=139.35
0326 LET L[50]=110.31
0327 LET L[51]=101.57
0328 LET L[53]=138.14
0329 LET L[54]=123.23
0330 LET L[56]=111.52
0331 LET L[57]=102.09
0332 LET L[60]=128.07
0333 LET L[62]=115.64
0334 LET L[63]=105.3
0335 LET L[65]=142.73
0336 LET L[66]=124.64
0337 LET L[68]=141.33
0338 LET L[69]=117.23
0339 LET L[72]=130.06
0340 LET L[74]=141.71
0341 LET L[75]=121.4
0342 LET L[78]=140.03
0343 LET L[81]=128.32
0344 LET L[84]=119.33
0345 LET L[87]=134.79
0346 LET L[90]=124.12
```

Fabrication

Fabrication of plywood stressed-skin panels (PSSPs) is concisely yet thoroughly described in a publication available upon request.[7] The publication emphasizes the need for adequate gluing in order to develop the composite action of plywood stressed-skins and the stringers. Results from mechanical-pressure gluing have been found to be generally superior to nail-gluing (latter, properly performed, is the basis for the design section herein, however); supplies needed for nailing may have to be estimated in advance, for which the following extract will be useful:[7(p.6)]

> "Nails shall be at least . . . 6d for 1/2" to 7/8" plywood, 8d for 1" to 1-1/8" plywood, . . . spaced not to exceed . . . 4" (along the framing members) for plywood 1/2" and thicker, using one line for lumber 2" thick or less, and two lines for lumber more than 2" and up to 4" thick (wide)."*

Glue, recommended for use in accordance with the manufacturers' recommendations, should be one of the two following types: Interior, for use when the equilibrium moisture content of the materials used does not exceed 18%, may be casein type with a mold inhibitor, conforming with ASTM Specification D3024; Exterior, for higher moisture contents, conforming to ASTM Specification D2559.

Nailing without gluing simply does not exploit the strength of PSSPs and the capabilities of their materials - the nails can too easily yield along the grain of the stringers so that they are inadequate as a shear transfer mechanism. The sparse test data found clearly show concern with deflection, not flexural, behavior as the controlling criterion, thus ultimate strength is not considered.

In the absence of some kind of ultimate strength behavior tests, the author has no basis for a recommendation, even heavily qualified, on the relative strength of nailed-only to nail- or pressure-glued PSSPs.

---

* Plywood thicknesses mentioned, 1/2", 7/8", 1" and 1-1/8" have SI (metric) equivalents of 13, 22, 25 and 29 mm, respectively. Lumber thicknesses mentioned, 2" and 4", are nominal (actual are 1½" and 3½"; or 38 and 89 mm).

Further Work

As mentioned in the section on "Design Stresses . . ." above, tests for ultimate strength (i.e., through to failure/collapse, recording full load-deflection history including time) under dynamic loadings, or even under static loadings if well into the plastic range, are badly needed as a better basis for design of PSSPs as blast closures. With such information, one might be, for example, justified in design procedure use of numerical integration of the equation of motion, instead of the less rigorous approach of using a step-pulse loading of infinite duration, as has been done in preparing the design procedure above. Further, the wood design stresses would be better known, of course, as would the composite behavior including the primary cause of each test PSSP's failure mode.

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NOTATION

A	total x-section area of all stringers
A	x-section area of parallel-grain plies outside the critical plane for rolling shear
A	total x-section area of all stringers and skins $A_{//}$ (beam-columns)
$A_{//}$	x-section area (finished) of plies // stringers, in each skin
$A_{\perp}$	x-section area (finished) of plies $\perp$ stringers, in each skin
b, b_b, b_t	basic stringer spacing; subscripts are for bottom and top skins, respectively
C	factor for maximum allowable deflection (usually based on LL only)
c	distance from neutral axis (for deflection or bending, as locally defined) to extreme fibre (of skin under check)(see $\bar{y}$)
d	moment arms for various x-sectional areas (subscripted A's), used in I_g and I_n calculations
d_s	$= c - y'$
E	modulus of elasticity
E_{st}	E of stringers
(EI_g)	panel parameter, calculated using neutral axis for *deflection*
(EI_n)	panel parameter, calculated using neutral axis for bending moment
F	allowable stress, general
F	allowable splice-plate stress multiplied by proportion of panel width actually spliced
F_c	allowable stress, compression in plane of plies // stringers
F_{c}	allowable stress, compression // grain in stringers
$F_{c\perp}$	allowable stress, bearing on plywood face
F_s	allowable stress, rolling shear
F_t	allowable stress, tension in plane of plies // stringers
F_t	allowable stress, tension // grain in stringers
F_v	allowable stress, horizontal shear, in stringers
G	modulus of rigidity in stringers
I	moment of inertia, total x-sectional area (finished) of all stringers
I	moment of inertia, in direction $\perp$ stringers, of top skin $A_{\perp}$
I_g	gross I of total panel x-section about deflection N.A.

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NOTATION (concluded)

I_n gross I of total panel x-section about bending N.A.

I_o gross moment of inertia of x-section portion about own centroidal axis

$I_{//}$, $I_{\perp}$ moment of inertia for plies, corresponding to $A_{//}$ and $A_{\perp}$ areas

ℓ clear span of panel, in direction of stringers

ℓ_e plywood end bearing length required at <u>each</u> end of panel

ℓ' panel width (skins only), perpendicular to ℓ

ℓ'' clear distance between stringers

p design LL or TL (use load related to assumed C factor)

p_a allowable axial load (TL) in beam-column

p_b allowable load (TL) - bending moment

p_d allowable load (TL) - panel deflection

p_{dm} same as p_m but specifically for dynamic loads/loadings

p_m smallest of calculated allowable transverse loads (TL)(in PSSPs for: deflection, bending moment, rolling shear and horizontal shear)

p_p allowable load (TL) - tension splice-plate

p_s allowable load (TL) - rolling shear

p_t allowable load (TL) - top skin deflection

p_v allowable load (TL) - horizontal shear

Q_s statical moment, about neutral axis for deflection, of parallel plies outside critical plane for rolling shear (see A above)

Q_v statical moment, about neutral axis for deflection, of stringers and $A_{//}$ plies x-sectional areas, taken <u>either</u> above <u>or</u> below that axis (used in horizontal shear allowable load calculations)

t glueline width of each stringer (used in $\Sigma F_s t$)

t sum of stringer widths, including side projecting portions

t_h thickness of header (solid across all panel stringers)

y moment arms used in neutral axes calculations

y' half-thickness of parallel plies outside critical plane for rolling shear (see Q_s and A above)

$\bar{y}$ distance from neutral axis to bottom extreme fibre (calculated in both deflection and bending moment calculations for neutral axis)

μ ductility ratio (maximum to elastic deflection, of a selected point, usual at mid-span or mid-height)

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Appendix A2

PLYWOOD STRESSED-SKIN PANELS (TWO-SIDED)

AS BEAM-COLUMNS

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CONTENTS

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Design

In the preceding Appendix A1, a design procedure, useful stresses, and typical designs were developed for plywood stressed-skin panels (PSSPs) and their estimated ultimate/collapse strength capacity for transverse (blast) loads. Such panels are of considerable interest to the overall purposes of the project work because abundant supplies of wood for stringers and plywood for skins are available in local lumberyards. Thus their potential is high for use in expedient upgrading of existing basements for shelter against the combined effects of a nuclear weapon detonation. These panels are treated in Appendix A1 in terms of their usefulness as closures, that is to resist transverse blast loads. The purpose of this appendix is to develop procedures for use of such panels as beam-columns, that is to resist axial blast loads, without or combined with transverse blast loads.

The basic references of Appendix A1 also contain information pertinent to beam-column design, or simple column design alone.[1(Sec.3),2] The formula provided for the latter is

$$P_a = 3.619\ (EI_g)\ /\ \ell^2 \qquad \text{(Eq.A2-1)}$$

or $$P_a = F_c A \qquad \text{(Eq.A2-2)}$$

whichever value is less, where*

P_a = allowable axial load (lb.)

(EI_g) = stiffness factor for moment deflection[1(Sec.2.4.3)] (lb-in.^{2} for full panel)(from Step 4, Appendix A1)

ℓ = clear span of member (simply-supported/pin-ended)(in.)

F_c = allowable compressive stress for plywood skins (psi),[2(p.17)] corrected for buckling[1(Sec.2.5.4)]

A = total x-sectional area of longitudinal grain material in both plywood skins and stringers (in.^{2})

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* Variables are defined herein at point of first use and in Notation at end of appendix.

The interaction formula provided for beam-columns is

$$P/P_a + (M/S)/F_c \leq 1 \qquad \text{(Eq.A2-3)}$$

where P = allowable axial load (lb.), under combined loading

M = allowable bending moment (in.-lb), under combined loading (from Step 11, Appendix A1)

$S = I_n / c$

in which S = section modulus of full panel (in.^{3})

I_n = bending moment of inertia of full panel (in.^{4})

c = distance from N.A. (bending) to extreme fiber in compression (in.)

Calculations are shown in Appendix A1, Figure 3 and Steps 7 and 8.

Assuming that the authors of References 1 and 2 used theory based on a solid, rectangular x-section column, then $I = bd^3/12$; using this for I_g and solving Equations 1 and 2 for F_c (also recalling that $r^2 = I/A$) leads to

$$F_c = (0.3016\ E) \,/\, (\ell/d)^2 = (\pi^2 E)/(2.727(\ell/r)^2)$$

The above two forms are found in Reference 3 (Section 301-E-2) under "Simple Solid-Column Design," indicating that the assumption above is correct. The latter of the two forms is Euler's equation[4(Eq.3&14)] in one of its many forms. Euler's equation is suitable for simply-supported/pin-ended long columns at <u>ultimate</u> (not allowable) load; it is non-conservative[4] when applied to columns with ℓ/r less than about 150, a value much too high for the uses contemplated herein; and the above constant, 2.727, is a factor of safety.

The serious concern with using the foregoing for blast loads is that various approximations have been introduced that can be collectively tolerated because of the allowable/working stress approach for normal uses. Where one is dealing with collapse strength of a column or beam-column, the design approach must take dynamic buckling directly into account and must consider deflection, usually at mid-height, caused by <u>all</u> loads, plus initial eccentricity if it is known or can be estimated. Thus it was concluded that a beam-column design approach should include iteration

toward an estimated total deflection from all sources, i.e., initial eccentricity if any, as well as deflection from moments due to transverse and axial loads.* The following design approach includes such iteration; it comes from Reference 4, Equation 18, and is converted to PSSP Notation, Appendix A1 and herein.

$$F_c = P_a/A + (M + P_a y)(c/I_n) \ \underline{\text{or}} \ = P_a/A, \text{whichever is less} \quad \text{(Eq.A2-4)}$$

where M = maximum moment caused by transverse loads (in.-lb)

y = deflection of column at M (in.)

The referenced source suggests iteration toward a final value for y, using for a first trial value that from M alone† in the second term of Equation A2-4. An approach to performing the suggested iteration follows, using the simply-supported/pin-ended member assumption stated earlier.

From Reference 6, for transverse loads (and modified to Notation herein):

$$M_{\text{mid-ht.}} = p_m \ell' \ell^2 / 8 \quad \text{(Eq.A2-5)}$$

$$\bar{y}_{\text{mid-ht.}} = 5 \, p_m \ell' \ell^4 / (384(EI_n)) \quad \text{(Eq.A2-6)}$$

thus,

$$y_{\text{mid-ht.}} = 5 \, \ell^2 \, (M_{\text{mid-ht.}} + P_a y) / (48(EI_n)) \quad \text{(Eq.A2-7)}$$

for combined transverse and axial loads, where

p_m = smallest of calculated allowable transverse loads (TL)(in PSSPs for: deflection, bending moment, rolling shear and horizontal shear)(psi)(from Appendix A1 design of PSSPs)

ℓ' = width of PSSP skins (perpendicular to stringers)(in.)

---

* An iterative numerical method for analyzing a beam-column is available.[5(App.A,p.6-160)]

† If there are no transverse loads, i.e., M = 0, there is no iteration. Use Equation 7 (with y dropping out) to find P_a; solve $P_a = F_c A$ and use smaller of the two P_a values; then, if deflection at mid-height is desired, solve Equation 4 for y.

(EI_n) = stiffness factor for bending moment[1] (Sec.2.5.3) (lb-in.^{2} for full panel)(from Step 8, Appendix A1)

For examining locations other than at mid-height of the (prismatic) beam-column, similar equations to Equations A2-5 to -7 would then be:[6]

$$M_x = p_m \ell' x\ (\ell - x)\ /\ 2 \qquad \text{(Eq.A2-8)}$$

$$\bar{y}_x = p_m \ell' x\ (\ell^3 - 2\ell x^2 + x^3)\ /\ (24(EI_n)) \qquad \text{(Eq.A2-9)}$$

thus,

$$y_x = (M_x + P_a y)\ (\ell^2 + \ell x - x^2)\ /\ (12(EI_n)) \qquad \text{(Eq.A2-10)}$$

for combined transverse and axial loads, where

x = location being examined (length along member)(in.)

The overall design approach just described should be applied with due regard to variation in units: some of the parameters are for full panel width, some would usually be applied to design of a one-inch wide strip of panel. All units, therefore, should be checked for values appropriate to one width or the other. All formulas herein are dimensionally consistent; there are no dimensions hidden in constants.

Design Procedure. Steps in the design procedure follow.

1. Assume a trial section and clear span/height (in direction of stringers); see Figure 1A, Appendix A1. Use only stress-graded stringers, with face grain of both plywood skins parallel to the stringers. Plan connections to PSSP such that loads are only axial, on pin ends, with or without uniform transverse/lateral loads.

2. Same as Step 2, Appendix A1.

3. Calculate A as in Step 3, Appendix A1.

4-6. Same as Steps 7 through 9, respectively, of Appendix A1. The c value needed later comes from Step 4 (either $\bar{y}$ in Figure 3A, Appendix A1, or the actual PSSP thickness minus $\bar{y}$); of course, if the same plywood is used for both top and bottom skins (as is recommended for this appendix), c is half the actual PSSP thickness.

At this point, values for the following variables used in this appendix are known: A (from Step 3), c (4), (EI_n) (5), F_c (6), I_n (5), ℓ(1), and ℓ' (1).

7. In Equation 7, set M = 0 and solve for P_a:

$$P_a = 48\ (EI_n)\ /\ (5\ \ell^2) \qquad \text{(Eq.A2-11)}$$

Also solve for P_a using, from Equation 4:

$$P_a = F_c A \qquad \text{(Eq.A2-12)}$$

Use P_a equal to the smaller of the two values found from Equations 11 and 12. This P_a is the maximum allowable load, applied axially when M = 0.

8. In Equation 4, use the longer form for F_c with M = 0 and solve for $y_{mid\text{-}ht.}$ (not needed if M = 0):

$$\bar{y}_{mid\text{-}ht.} = (I_n\ /\ c)\ (F_c/P_a - 1/A) \qquad \text{(Eq.A2-13)}$$

9. For combined transverse and axial loads, the PSSP must first be investigated, using Steps 1-14, Appendix A1, to find p_m, the peak transverse load capability with $P_a = 0$; the p_m value must be corrected to an equivalent static load p_m if design was for a dynamic loading p_{dm}. If the PSSP is one of those pre-designed and shown in Appendix A1, its p_{dm} value may be read from Figures 5-7 there, as the air blast peak overpressure (psi or kPa). However, such p_{dm} is based on the Design Stresses-Blast . . . section* of the appendix, which includes use of μ = 2 and a step pulse, meaning that the static equivalent p_m is 4/3 the chart value p_{dm} (still with design stresses greatly increased over those for normal, not blast-resistant, use). A value for μ and blast design stresses in beam-columns, in contrast to normal-use design stresses, are discussed in the next section.

Subscripts for mid-height will be dropped from here on, for convenience; the PSSP should be prismatic and without initial eccentricity,

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* Includes, at the end of that section, a definition of step pulse and the basic relationship $p_{dm} = p_m\ (1 - 1/(2\mu))$. It follows that $P_{da} = P_a(1 - 1/(2\mu))$.

therefore all M and y values will be for mid-height/mid-length for a vertical/horizontal beam-column.

10. Solve Equations 5 and 6 for M and y (when $P_a = 0$). (From Steps 7 and 8, values of P_a and related y (when M = 0) are known. Thus the two extreme values of transverse or axial load capacity, with their related mid-height deflections, are known at this point. These unique values will be identified as $M_{max.}$ (or its related $p_{m(max.)}$ of Step 9) and $P_{a(max.)}$ in the Steps below.)

11. Assume a value for $P_a < P_{a(max.)}$ and a first trial value* for y as that found in Step 10 (for $P_a = 0$).

12. Solve Equation 4 for M (which must be less than $M_{max.}$):

$$M = (I_n / c)\ (F_c - P_a / A) - P_a y \qquad \text{(Eq.A2-14)}$$

13. Solve Equation 7 using the trial y on the right-side. Compare the left-side y, found from solving Equation 7, with the trial y used. If the two y values are not in acceptable agreement (say, 1% to 5%), use the left-side value as the new trial value* of y and repeat Steps 12 and 13; otherwise, proceed with the next design step.

14. Find allowable p_m related to the final M of Step 12:

$$p_m = (M_{step\ 12} / M_{max})\ p_{m(max.)(step\ 9)}$$

This allowable p_m could also be found by using Equation 5 with the final M of Step 12, or Equation 6 with the final left-side y of Step 13.

15. With allowable P_a (Step 11) and p_m (Step 14) known, one pair of pertinent values for the assumed trial section PSSP has been found, besides the two pairs of values represented by $M_{max.}$ or $p_{m(max.)}$ ($P_a = 0$), and $P_{a(max.)}$ (M = 0), Step 10. Other pairs of values are found by repeating Steps 11-14. To complete the design, a new trial section(s) may have to be assumed, repeating Steps 1-14.

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* Of course the designer is free to select the first or later trial value(s) of y based on experience or simply guessing.

Design Stresses - Blast Protection Use versus Normal Use. The user of this appendix is referred to a section with the same title, appearing in Appendix A1; the information there is applicable to this appendix except for the last paragraph, which deals with a value for the ductility ratio μ.

For a value of the ductility ratio μ for beam-columns, $\mu = 1$ is recommended for use because of buckling considerations and the increases of normal use stresses already recommended for adoption. If a step pulse (defined in the Appendix A1 section) is appropriate, then the footnote to design Step 9 applies, thus $P_{da} = P_a/2$ and $p_{dm} = p_m/2$ (latter are allowable load from peak exterior blast incident overpressure and static uniform load capacity, respectively). It is possible that a significant rise-time should be applied to the axial blast load but probably not. However, the transverse blast load occurring inside a basement shelter is very likely to have a significant rise-time as well as a significant reduction in peak value from the blast peak exterior incident overpressure, due to room filling.* If a rough approximation must be suggested, it would be that $p_{dm} = p_m$ where only human-size doorways and typical basement windows constitute the apertures; large openings would indicate use of $p_{dm} = p_m$ times 3/4, even approaching 1/2; this suggested approach attempts to consider both lengthened rise-time and reduced peak value of overpressure in terms of that incident on the basement's exterior.

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* See published guidance on design for combined nuclear weapons effects shelter in previously published guidance on design for combined nuclear weapons effects in planned (new) basements, References 5 and 7, especially the latter's Appendix E appearing in Volume 3; the same Appendix E, written by J. R. Rempel, a colleague, was published in an earlier report, Reference 8; the Appendix E technique was used to produce a short section and two design graphs[7&8](pp.8-112 to -114) giving maximum interior pressure and time to reach such pressure, both in terms of V/A, room volume/total aperture area.

Further Work

The comments in the last section of Appendix A1, Further Work, apply fully to this appendix.

Obviously needed other work would be that on pre-designs, as in Appendix A1; design Step 15 indicates the amount of analytical work needed to obtain all possible pairs of values of P_a and p_m for just one assumed PSSP. Thus, graphical solutions are indicated, say, for each pre-designed PSSP of Appendix A1 (at least the symmetrical ones) showing p_m versus P_a values, with charts for clear spans/heights of 7, 9 and 11 ft.

NOTATION

A = total x-sectional area of longitudinal grain material in both plywood skins and stringers (in.^{2})

c = distance from N.A. (bending) to extreme fiber in compression (in.)

(EI_g) = stiffness factor for moment deflection[1(Sec.2.4.3)] (lb-in.^{2} for full panel)(from Step 4, Appendix A1)

(EI_n) = stiffness factor for bending moment[1(Sec.2.5.3)] (lb-in.^{2} for full panel)(from Step 8, Appendix A1)

F_c = allowable compressive stress for plywood skins (psi),[2(p.17)] corrected for buckling[1(Sec.2.5.4)]

I_n = bending moment of inertia of full panel (in.^{4})

ℓ = clear span of member (simply-supported/pin-ended)

ℓ' = width of PSSP skins (perpendicular to stringers)(in.)

M = allowable bending moment (in.-lb), under combined loading (from Step 11, Appendix A1)

M = maximum moment caused by transverse loads (in.-lb)

P = allowable axial load (lb.), under combined loading

P_a = allowable axial load (lb.)

$P_{da} = P_a\ (1 - 1/(2\mu))$ (for step pulse)(lb.)

$p_{dm} = p_m\ (1 - 1/(2\mu))$ (for step pulse)(psi)
= allowable load from peak exterior blast incident overpressure

p_m = smallest of calculated allowable transverse loads (TL)(in PSSPs for deflection, bending moment, rolling shear and horizontal shear) (psi)(from Appendix A1 design of PSSPs)

x = location being examined (length along member)(in.)

y = deflection of column at M (in.)

$\bar{y}$ = deflection of column at M (transverse loads only)

$\bar{y}$ = distance from N.A. (deflection or bending moment) to bottom extreme fibre

μ = ductility ratio (maximum deflection / elastic deflection)

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* Now SRI International.

Appendix A3

PLYWOOD USE FOR CLOSURES - DESIGN

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CONTENTS

TABLES

Background

Appendices A1 and A2, in their early paragraphs, describe plywood uses toward meeting the need for expedient aperture closures and added overhead floor system supports, respectively, in the upgrading of existing basements for shelter use against the combined effects of a nuclear weapons detonation. This Appendix A3 closes Appendix A, Plywood Applications, by describing a design approach for simple use of plywood for closures, especially over those many shelter openings having a rather short span in at least one of its two directions.

Approach

Use was made of two publications and telephone discussions[1-3] in developing a design procedure for use of plywood to close apertures in existing basements. The tables of the simplified publication[2] could not be reproduced through use of the design manual[1] procedures; requested clarification brought the recommendation that the latter be used for the purposes contemplated herein.[3]

As before, in Appendices A1 and A2, design formulas[1(pp.22-3,Sec.4)] were converted to the Notation herein and made dimensionally consistent. The revised formulas follow; plywood weight is ignored as dead load, and single spans, uniform loads, and simple supports are assumed.

The user is cautioned to apply care in units used in entering all values in the equations below; all equations are dimensionally consistent, i.e., there are no units hidden in the constants.

A. For uniform loads based on allowable bending stress:

$$p_b = 8 F_b S / \ell^2 \qquad \text{(Eq.A3-1)}^\dagger$$

where*

p_b = allowable load - bending moment (psi)

F_b = allowable bending stress (psi)

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* Variables are defined herein at point of first use and in Notation at end of appendix.

† In Eq. A3-1, clear span can be used (per Reference 3 fonecon of 1/6/78).

S = effective section modulus (in.^{3}/in.width)

ℓ = clear span (in.)

B. For uniform loads based on allowable rolling shear stress:

$$p_s = 2\ F_s\ (Ib/Q)\ /\ \ell \quad \text{(Eq.A3-2)}$$

where

p_s = allowable load - rolling shear stress (psi)

F_s = allowable rolling shear stress (psi)

(Ib/Q) = rolling shear constant (in.^{2}/in. width)

ℓ = clear span (in.)

The useful allowable load p_m then becomes:

$$p_m = p_b \text{ or } p_s \text{ whichever is smaller (psi)} \quad \text{(Eq.A3-3)}$$

C. For bending deflection (elastic) under uniform load:

$$y_b = p_m \ell^4\ /\ (76.8\ I\ (1.1\ E)) \quad \text{(Eq.A3-4)*}$$

where

y_b = bending deflection (elastic) under uniform load (in.)

I = effective moment of inertia (in.^{4}/in. width)

E = modulus of elasticity (psi)

D. For shear deflection (elastic) under uniform load:

$$y_s = p_m C t^2 \ell^2\ /\ (106\ EI) \quad \text{(Eq.A3-5)}$$

where

y_s = shear deflection (elastic) under uniform load (in.)

C = 120 or 60, for panels applied with face grain perpendicular to or parallel to supports, respectively.

t = nominal panel thickness (in.)

E. For combined bending and shear deflection (elastic) under uniform load: either (a) add y_b and y_s from Equations 4 and 5; or (b) use Equation 4 only, but with the constant 1.1 dropped from the equation.

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* Modified very slightly as to ℓ from Ref. 1, for simplification and because of negligible effect on the uses made of deflection calculations herein.

F. For plywood face bearing under uniform load (at ends over simple supports):

$$\ell_e = \ell / (2(F_{c\perp}/p_m - 1)) \qquad \text{(Eq.A3-6)}$$

where

ℓ_e = required plywood (face) end bearing length at each end of panel (in.)

$F_{c\perp}$ = allowable bearing stress on plywood face, for load perpendicular to plane of outer ply actually in bearing (psi)

It is recommended that ℓ_e be at least 1.5 in. (38 mm).

Design Procedure

The suggested design procedure consists of the following Steps:

1. Assume use of a particular plywood type, grade, nominal thickness t, and face ply(ies) species group (pp. 9, 14 and 15)† except that the latter must not be #5. Also assume that panel is uniformly loaded and simply supported,‡ and assume value for span ℓ (in.). Neglect the plywood weight as a DL.

2. Determine values (p. 16)† for I, S (=KS),† and (Ib/Q), taking care to correct the units to in.^{4}, in.^{3}, and in.^{2} (all per in. width), respectively. Take care to use proper values for plywood used with the face grain running parallel to the span (cols. 5-7)† or perpendicular to the span (col. 9-11),† as well as the appropriate table (1 or 2)† and section (Unsanded, Sanded, or Touch-Sanded Panels).† If permitted by available supplies, plywood panels are used with the face grain running parallel to the span, which takes advantage of the stronger direction of the plywood.

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† See Reference 1; it is necessary that the designer hold this reference.
‡ On two opposite sides; but Step 7 extends the procedure to plywood panels supported on four sides.

3. Study the plywood data (p.14)* and select appropriate use condition (Wet or Dry) and grade stress level (S-1, -2, or -3). Determine values (p. 17)* for F_b, F_s, $F_{c\perp}$, and E (all psi).

4. Solve Equations 1-3 for p_b, p_s, and p_m, respectively.[1,3]

5. Solve Equation 6 for ℓ_e.

6. If deflections are needed or desired, either:[1,3]

   (a) Solve Equations 4 and 5 for y_b and y_s, respectively ; then $y = y_b + y_s$; or

   (b) Solve Equation 4 with the value 1.1 deleted on right side; then $y = y_b$.

7. For plywood panels supported on four sides, the procedure is as follows:[2,3]

   (a) Complete Steps 1-4 and 6 for each span direction, finding p_m and y for each direction;

   (b) Reduce the p_m value associated with the larger y, by multiplying that p_m by the ratio of the smaller y to the larger y. The two y values will then be equal, and the total capacity p_m of the panel supported on four sides will be the sum of the p_m just reduced and the unchanged p_m associated with the smaller y of Step 7a; use the latter two p_m values to *find* ℓ_e in each direction (Step 5).

Design Stresses - Blast Protection Use versus Normal Use

An Appendix A1 section with the same title applies fully herein, excepting that $\mu = 3$ is recommended for this appendix; thus, $p_{dm} = (5/6)\ p_m$, and F_b and F_s (but not $F_{c\perp}$ and E) are multiplied by four.

Typical Designs of Plywood Panels as Closures

Data in the preceding sections have been used to prepare the typical designs of plywood panels as closures shown in Tables A3-1A, -1B, -1C and -2. Computer programs used are listed in Table A3-3.

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* See Reference 1; it is necessary that the designer hold this reference.

Table A3-1A PLYWOOD PANELS AS CLOSURES (ONE-WAY)

Plywood panels considered herein are each stamped with American Plywood Association (APA) Type (Interior or Exterior), Grade and, in most cases, with Face Ply Species Group(s) (the latter exception is discussed further below), as follows:

Plywood Type and Grade	Table A3-1B&C Block Nos.
C-D INTERIOR (APA),* usual:	3,11
If "interior with exterior glue" is specified:	2,10
UNDERLAYMENT INTERIOR (APA), usual:	8,16
If "interior with exterior glue" is specified:	7,15
C-D PLUGGED INTERIOR (APA), usual:	8,16
If "interior with exterior glue" is specified:	7,15
2.4.1 INTERIOR (APA), usual:	18
If "interior with exterior glue" is specified:	17
APPEARANCE GRADES (Interior) (APA),† usual:	6,14
If "interior with exterior glue" is specified:	5,13
C-C EXTERIOR (APA)*	1,9
UNDERLAYMENT EXTERIOR (APA)	7,15
C-C PLUGGED EXTERIOR (APA)	7,15
APPEARANCE GRADES (Exterior) (APA),‡ with Surface A or C, face & back:	4,12
With Surface B face or back:	5,13

* Face Ply Species Groups are as follows: When stamped 24/0 on 1/2 in. (13 mm) thick plywood, Group 4; 32/16, Group 1; on 3/4 in. (19 mm): 42/20, Group 3; 48/24, Group 1.

† Generally applied where a high quality surface is required; includes N-N, N-A, N-B, N-D, A-A, A-B, A-D, B-B and B-D INTERIOR (APA) Grades.

‡ Generally applied where a high quality surface is required; includes A-A, A-B, A-C, B-B, B-C, HDO and MDO EXTERIOR (APA) Grades.

Table A3-1B PLYWOOD PANELS AS CLOSURES (ONE-WAY)*

Block No.	PLYWOOD Nom. Th. in.	Surface Finish	Grade Str. Level	Face Ply Grp	(SIDE-ON) PEAK AIR BLAST OVERPRESSURE VS. CL. SPAN — Clear Span, in. 4	6	8	10	12	14	16	18	20	22	24	26	28
1.	1/2	UNSANDED	S-1	1	31	21	15	11	8	6	psi						
				2,3	31	21	12	8	5								
				4	31	20	11	7	5								
2.	1/2	UNSANDED	S-2	1	31	21	14	9	6	5							
				2,3	31	18	10	7	5								
				4	31	17	10	6									
3.	1/2	UNSANDED	S-3	1	28	19	14	9	6	5							
				2,3	28	18	10	7	5								
				4	28	17	10	6									
4.	1/2	SANDED	S-1	1	36	24	18	12	8	6	5						
				2,3	36	23	13	8	6								
				4	36	22	12	8	5								
5.	1/2	SANDED	S-2	1	36	24	15	10	7	5							
				2,3	36	20	11	7	5								
				4	36	18	10	7	5								
6.	1/2	SANDED	S-3	1	32	21	15	10	7	5							
				2,3	32	20	11	7	5								
				4	32	18	10	7	5								
7.	1/2	TOUCH-S.	S-2	1	31	21	16	10	7	5							
				2,3	31	20	11	7	5								
				4	31	19	10	7	5								
8.	1/2	TOUCH-S.	S-3	1	28	19	14	10	7	5							
				2,3	28	19	11	7	5								
				4	28	19	10	7	5								
9.	3/4	UNSANDED	S-1	1	50	33	25	20	15	11	9	7	6	5			
				2,3	50	33	24	16	11	8	6	5					
				4	50	33	23	15	10	8	6	5					
10.	3/4	UNSANDED	S-2	1	50	33	25	18	13	9	7	6	5				
				2,3	50	33	21	13	9	7	5						
				4	50	33	19	12	9	6	5						
11.	3/4	UNSANDED	S-3	1	45	30	23	18	13	9	7	6	5				
				2,3	45	30	21	13	9	7	5						
				4	45	30	19	12	9	6	5						
12.	3/4	SANDED	S-1	1	58	39	29	20	14	10	8	6	5				
				2,3	58	39	22	14	10	7	5						
				4	58	37	21	13	9	7	5						
13.	3/4	SANDED	S-2	1	58	39	26	17	12	8	6	5					
				2,3	58	33	19	12	8	6	5						
				4	58	31	17	11	8	6							
14.	3/4	SANDED	S-3	1	53	35	26	17	12	8	6	5					
				2,3	53	33	19	12	8	6	5						
				4	53	31	17	11	8	6							
15.	3/4	TOUCH-S.	S-2	1	51	34	25	17	12	9	7	5					
				2,3	51	34	20	13	9	6	5						
				4	51	33	18	12	8	6	5						
16.	3/4	TOUCH-S.	S-3	1	46	31	23	17	12	9	7	5					
				2,3	46	31	20	13	9	6	5						
				4	46	31	18	12	8	6	5						
17.	1-1/8	TOUCH-S.	S-2	1-3		52	39	31	25	19	14	11	9	8	6	5	5
18.	1-1/8	TOUCH-S.	S-3	1-3		51	38	30	25	19	14	11	9	8	6	5	5

* Face ply grain running in span direction (i.e., perpendicular to the two supports). Required bearing length at each end (beyond clear span) is 1½ in. (38 mm) in all cases.

Table A3-1C PLYWOOD PANELS AS CLOSURES (ONE-WAY)*

Block No.	PLYWOOD Th. mm	Surface Finish	Grade Str. Level	Face Ply Grp	(SIDE-ON) PEAK AIR BLAST OVERPRESSURE VS. CLEAR SPAN — Clear Span, mm: 100	150	200	250	300	350	400	450	500	550	600	650
1.	13	UNSANDED	S-1	1	216	144	108	78	54	40	kPa					
				2,3	216	144	85	55	38							
				4	216	144	81	52	36							
2.	13	UNSANDED	S-2	1	216	144	101	64	45							
				2,3	216	130	73	47								
				4	216	120	68	43								
3.	13	UNSANDED	S-3	1	196	130	98	64	45							
				2,3	196	130	73	47								
				4	196	120	68	43								
4.	13	SANDED	S-1	1	249	166	125	84	58	43						
				2,3	249	164	92	59	41							
				4	249	155	87	56	39							
5.	13	SANDED	S-2	1	249	166	108	69	48	35						
				2,3	249	140	79	50	35							
				4	249	130	73	47								
6.	13	SANDED	S-3	1	226	151	108	69	48	35						
				2,3	226	140	79	50	35							
				4	226	130	73	47								
7.	13	TOUCH-S.	S-2	1	219	146	110	71	49	36						
				2,3	219	143	80	51	36							
				4	219	132	74	48								
8.	13	TOUCH-S.	S-3	1	199	132	99	71	49	36						
				2,3	199	132	80	51	36							
				4	199	132	74	48								
9.	19	UNSANDED	S-1	1	352	235	176	141	110	81	62	49	40			
				2,3	352	235	173	111	77	57	43	34				
				4	352	235	165	105	73	54	41					
10.	19	UNSANDED	S-2	1	352	235	176	131	91	67	51	40				
				2,3	352	235	149	95	66	49	37					
				4	352	235	137	88	61	45	34					
11.	19	UNSANDED	S-3	1	319	212	159	127	91	67	51	40				
				2,3	319	212	149	95	66	49	37					
				4	319	212	137	88	61	45	34					
12.	19	SANDED	S-1	1	406	271	203	143	99	73	56	44	36			
				2,3	406	271	156	100	70	51	39					
				4	406	264	149	95	66	49	37					
13.	19	SANDED	S-2	1	406	271	184	118	82	60	46	36				
				2,3	406	238	134	86	60	44	34					
				4	406	220	124	79	55	40						
14.	19	SANDED	S-3	1	368	245	184	118	82	60	46	36				
				2,3	368	238	134	86	60	44	34					
				4	368	220	124	79	55	40						
15.	19	TOUCH-S.	S-2	1	357	238	178	124	86	64	49	38				
				2,3	357	238	141	91	63	46	35					
				4	357	233	131	84	58	43						
16.	19	TOUCH-S.	S-3	1	323	215	162	124	86	64	49	38				
				2,3	323	215	141	91	63	46	35					
				4	323	215	131	84	58	43						
17.	29	TOUCH-S.	S-2	1-3		361	271	216	180	132	101	80	65	54	45	38
18.	29	TOUCH-S.	S-3	1-3		354	266	213	177	132	101	80	65	54	45	38

* Face ply grain running in span direction (i.e., perpendicular to the two supports). Required bearing length at each end (beyond clear span) is 1½ in. (38 mm) in all cases.

Table A3-2 PLYWOOD PANELS AS CLOSURES (TWO-WAY)

The purpose of this Table is to provide conversion percentages (increases) so that the user can use the data of Tables A3-1B and C to obtain overpressure versus clear span data for two-way plywood panels (that is, supported on all four sides of the opening/aperture to be closed).

This Table is based on using plywood panels with their face ply grain running in the direction of the shorter of the aperture's two clear spans. Its results are expressed in terms of the ratio of the longer to the shorter of the two clear spans; such results are expressed as percentage increases in overpressure resistance values applied to the values in Tables A3-1B and C, with such increases related to the BLOCK NUMBERS of those tables.

Recommended support bearing length on all four sides is $1\frac{1}{2}$ in. (38 mm.).

TABLES A3-1B&C BLOCK NUMBERS	RATIO OF LONGER TO SHORTER CLEAR SPANS 1:1	1.25:1	1.5:1	2:1
1 - 3	6%	2%	1%	*
4 - 6	23	10	5	1%
7, 8	7	3	1	*
9 - 11	15	6	3	1
12 - 14	47	19	9	3
15, 16	19	8	4	1
17, 18	43	18	9	3

* Less than 1/2%

Table A3-3 LISTING OF COMPUTER PROGRAMS (HLMPP1, 2 AND 3) USED FOR TABLES A3-1B AND C

HLMPP1

```
0100 REM   DESIGN OF PLYWOOD PANELS AS CLOSURES (APP.A3,HLM RPT 10/77)
0101 REM
0110 DIM M[50],S[50],Q[50],F[50],G[50],H[50]
0120 DIM A$[3],B$[3],C$[5],D$[8],E$[6],F$[8],G$[3],H$[3],I$[3],J$[3]
0122 DIM K$[3]
0124 DIM Z$[1]
0150 LET A$="1/2"
0152 LET B$="3/4"
0154 LET C$="1-1/8"
0156 LET D$="UNSANDED"
0158 LET E$="SANDED"
0160 LET F$="TOUCH-S."
0162 LET G$="S-1"
0164 LET H$="S-2"
0166 LET I$="S-3"
0168 LET J$="2,3"
0170 LET K$="1-3"
0172 LET Z$=" "
0199 REM SECTION PROPERTIES FOR 1/2 IN.
0200  FOR I=1 TO 9
0202  LET M[I]=.086/12
0204  LET S[I]=.247/12
0206  LET Q[I]=4.189/12
0210  NEXT I
0220  FOR I=10 TO 18
0222  LET M[I]=.077/12
0224  LET S[I]=.266/12
0226  LET Q[I]=4.834/12
0230  NEXT I
0240  FOR I=19 TO 24
0242  LET M[I]=.083/12
0244  LET S[I]=.271/12
0246  LET Q[I]=4.252/12
0250  NEXT I
0259 REM SECTION PROPERTIES FOR 3/4 IN.
0260  FOR I=25 TO 33
0262  LET M[I]=.243/12
0264  LET S[I]=.501/12
0266  LET Q[I]=6.823/12
0270  NEXT I
0280  FOR I=34 TO 42
0282  LET M[I]=.197/12
0284  LET S[I]=.452/12
0286  LET Q[I]=7.881/12
0290  NEXT I
0300  FOR I=43 TO 48
0302  LET M[I]=.22/12
0304  LET S[I]=.477/12
0306  LET Q[I]=6.917/12
0310  NEXT I
0320  FOR I=49 TO 50
0322  LET M[I]=.653/12
0324  LET S[I]=.995/12
0326  LET Q[I]=9.933/12
0330  NEXT I
0399 REM ALLOWABLE STRESSES (WITH DYNAMIC MULTIPLIERS)
0400 LET H[49]=H[50]=340
0410  FOR I=1 TO 46 STEP 3
0412  LET H[I]=340
0414  LET H[I+1]=210
0416  LET H[I+2]=160
0418  NEXT I
0420  FOR I=1 TO 50
0422  LET F[I]=G[I]=0
0424  NEXT I
0430  FOR I=1 TO 10 STEP 9
0432  LET F[I]=2000*4
0433  LET F[I+1]=1400*4
0434  LET F[I+2]=1330*4
0436  NEXT I
0440  FOR I=25 TO 34 STEP 9
0442  LET F[I]=2000*4
0444  LET F[I+1]=1400*4
0446  LET F[I+2]=1330*4
0448  NEXT I
0450  FOR I=1 TO 46 STEP 3
0452  IF F[I]>0 THEN 460
0454  LET F[I]=1650*4
0456  LET F[I+1]=1200*4
0458  LET F[I+2]=1110*4
0460  NEXT I
0470 LET F[49]=F[50]=1650*4
0480  FOR I=7 TO 16 STEP 9
0482  LET G[I]=G[I+1]=G[I+2]=48*4
0484  NEXT I
0490  FOR I=22 TO 24
0492  LET G[I]=48*4
0494  NEXT I
0500  FOR I=31 TO 40 STEP 9
0502  LET G[I]=G[I+1]=G[I+2]=48*4
0504  NEXT I
0510  FOR I=46 TO 48
0512  LET G[I]=48*4
0514  NEXT I
0520 LET G[49]=56*4
0522 LET G[50]=55*4
0530  FOR I=1 TO 48
0532  IF G[I]>0 THEN 536
0534  LET G[I]=53*4
0536  NEXT I
0600 IMAGE 5AXX,8AXX,3AXX,D
0601 IMAGE 5AXX,8AXX,3AXX,3A
```

Table A3-3 (continued)

```
0605  GOSUB 710
0610  PRINT USING 600;A$,D$,G$,1
0612  GOSUB 700
0615  PRINT USING 600;A$,D$,H$,1
0617  GOSUB 700
0620  PRINT USING 600;A$,D$,I$,1
0622  GOSUB 700
0625  PRINT USING 600;A$,E$,G$,1
0627  GOSUB 700
0630  PRINT USING 600;A$,E$,H$,1
0632  GOSUB 700
0635  PRINT USING 600;A$,E$,I$,1
0637  GOSUB 700
0640  PRINT USING 600;A$,F$,H$,1
0642  GOSUB 700
0643  PRINT USING 600;A$,F$,I$,1
0644  GOSUB 700
0645  PRINT USING 600;B$,D$,G$,1
0647  GOSUB 700
0650  PRINT USING 600;B$,D$,H$,1
0652  GOSUB 700
0655  PRINT USING 600;B$,D$,I$,1
0657  GOSUB 700
0660  PRINT USING 600;B$,E$,G$,1
0662  GOSUB 700
0665  PRINT USING 600;B$,E$,H$,1
0667  GOSUB 700
0670  PRINT USING 600;B$,E$,I$,1
0672  GOSUB 700
0675  PRINT USING 600;B$,F$,H$,1
0677  GOSUB 700
0680  PRINT USING 600;B$,F$,I$,1
0682  GOSUB 700
0685  PRINT USING 601;C$,F$,H$,K$
0687  PRINT USING 601;C$,F$,I$,K$
0690  GOSUB 710
0699  GOTO 900
0700  PRINT USING 601;Z$,Z$,Z$,J$
0702  PRINT USING 600;Z$,Z$,Z$,4
0704  RETURN
0710   FOR I=1 TO 10
0712   PRINT
0715   NEXT I
0717  RETURN
0900   FOR I=1 TO 50
0902   LET A=4
0903   LET B=32
0904   LET C=2
0905   LET G=5
0907  REM    SIDE-ON OVERPR (PSI) & REQD END BEAR.LENGTH (IN) VS CL.SPAN ROUTINE
0908  REM     (TO CUT OUT BEAR.LENGTH, USE:    952  GOTO 978  )
0910    FOR L=A TO B STEP C
0912   GOSUB 920
0915   GOTO 936
0920   LET P1=8*F[I]*S[I]/L^2
0922   LET P2=2*G[I]*Q[I]/L
0924   IF P1<P2 THEN 930
0926   LET P0=P2
0928   GOTO 932
0930   LET P0=P1
0932   REM    USING MU=3 FOR INSTANT RISE, INFINITE DURATION BLAST LOAD
0934   LET P=INT(P0*5/6+1/2)
0935   RETURN
0936   IF P<G THEN 948
0938   IF L=B THEN 944
0940   PRINT USING "#,XDDXX";P
0942   GOTO 950
0944   PRINT USING "XDDXX";P
0946   GOTO 951
0948   PRINT USING "4X"
0949   GOTO 951
0950   NEXT L
0951   FOR L=A TO B STEP C
0952   GOSUB 920
0953   LET L1=L/(2*(H[I]/P0-1))
0954   LET L1=INT(2*L1+.8)/2
0956   IF L1>1.6 THEN 960
0958   LET L1=1.5
0960   IF P<G THEN 972
0962   IF L=B THEN 968
0964   PRINT USING "#,D.DXX";L1
0966   GOTO 976
0968   PRINT USING "D.DXX";L1
0970   GOTO 978
0972   PRINT USING "4X"
0974   GOTO 978
0976   NEXT L
0978  NEXT I
0990  GOSUB 710
9999  END
```

<u>HLMPP2</u>

```
0102  REM   CHANGES ONLY TO HLMPP1: TO CONDENSE TABLE & OMIT REQ'D BEARING
0103  REM      LENGTH EA.END
0104  REM
0940  PRINT USING "#,DDXX";P
0944  PRINT USING "DDXX";P
0952  GOTO 978
```

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Table A3-3 (concluded)

<u>HLMPP3</u>

```
0102 REM   CHANGES ONLY TO HLMPP1: TO CONDENSE TABLE & OMIT REQ'D BEARING
0103 REM      LENGTH EA.END, PLUS SHIFT TO METRIC OUTPUT
0104 REM
0150 LET A$="13"
0152 LET B$="19"
0154 LET C$="29"
0600 IMAGE 2AXX,8AXX,3AXX,D
0601 IMAGE 2AXX,8AXX,3AXX,3A
0906 LET G=INT(G*6.89476+1/2)
0921 LET P1=P1/(.984252^2)
0923 LET P2=P2/.984252
0934 LET P=INT(P0*5/6*6.89476+1/2)
0940 PRINT USING "#,DDDXX";P
0944 PRINT USING "DDDXX";P
0952 GOTO 978
```

Further Work

The comments in the last section of Appendix A1, Further Work, apply also to this appendix.

NOTATION

C	120 <u>or</u> 60, for panels applied with face grain perpendicular to <u>or</u> parallel to supports, respectively
E	modulus of elasticity (psi)
F_b	allowable bending stress (psi)
$F_{c\perp}$	allowable bearing stress on plywood face, for load perpendicular to plane of outer ply actually in bearing (psi)
F_s	allowable rolling shear stress (psi)
I	<u>effective</u> moment of inertia (in.^{4}/in. width)
(Ib/Q)	rolling shear constant (in.^{2}/in.width)
L	span center-to-center of supports (in.)
ℓ	clear span (in.)
ℓ_e	required plywood (face) end bearing length at <u>each</u> end of panel (in.)
p_b	allowable load - bending moment (psi)
p_{dm}	dynamic (blast) *uniform* load capacity (psi)
p_m	smaller of p_b or p_s = static uniform load capacity (psi)
p_s	allowable load - rolling shear stress (psi)
S	<u>effective</u> section modulus (in.^{3}/in. width)
t	nominal panel thickness (in.)
y	deflection (elastic) under uniform load (in.)
y_b	bending deflection (elastic) under uniform load (in.)
y_s	shear deflection (elastic) under uniform load (in.)

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REFERENCES

1. Plywood Design Specifications (PDS), American Plywood Association, 1119 A Street, Tacoma, Washington 98401, Revised December 1976.

2. Plywood Design Manual - Shelving, American Plywood Association, 1119 A Street, Tacoma, Washington 98401, 1975.

3. Personal communications: Author with Wm. A. Baker, P.E., Head, Engineering Service, Applied Research Service, American Plywood Association, 1119 A Street, Tacoma, Washington 98401, July 22, 1977; and with James Elliott of Mr. Baker's staff, August 1, 1977.

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Appendix B

DESIGN OF WOOD BEAMS - SIMPLY SUPPORTED*

Extracted, retaining original pagination and figure numbers, as published in:

Murphy, H. L., and J. E. Beck, Slanting for Combined Nuclear Weapons Effects: BLAST-RESISTANT DESIGN/ANALYSIS WITH EXAMPLES, Stanford Research Institute Final Report, for Defense Civil Preparedness Agency, December 1974. (AD-A016 631)

Murphy, H. L., J. R. Rempel, and J. E. Beck, SLANTING IN NEW BASEMENTS FOR COMBINED NUCLEAR WEAPONS EFFECTS: A Consolidated Printing of Four Technical Reports, 3 Vols., Stanford Research Institute Technical Reports, for Defense Civil Preparedness Agency, October 1975. (AD-A023 237)

WITH A NEW ADDENDUM ON CLOSURE APPLICATIONS

* Chart solutions herein are for only simply supported (SS) beams; however, the design procedure also covers propped cantilever (PC) and fixed-fixed (FF) support conditions, as does the computer program (Table B-1) of the new Addendum.

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CONTENTS

TABLE

FIGURES

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G. Wood Beams - Simply Supported

The wood contemplated for use under the design procedures described herein is structural or stress-graded lumber, which has been carefully graded in accordance with the standard grading rules for the appropriate trade association (e.g., References 52 and 53). A complete list of such associations is available.[54] It is urged that all lumber contemplated for shelter use - specifically, lumber in structural components or members whose stress-resisting capability is important to the survival of shelterees (in contrast to such things as a door cross-brace that simply holds together the structurally significant members) - be reinspected and regraded by particularly qualified personnel using the appropriate association's grading rules.

Other items for the designer's general consideration are:

- The lack of homogeneity in wood members dictates that every effort be made to design wood structural members so that they interact in such a manner as to transfer load from a weaker or below-standard member to the better members. Examples are: really good blocking between floor joists; and use of tongue-and-groove planking as members used flat in a blast door.

- Only very tight knots (preferably no knots) should be accepted in a situation such as that of an unclad wood shelter blast door where an air blast loading could make a missile or bullet out of a knot that is even slightly loose.

- Metal cladding may be indicated for some situations where wood is used, such as exposure to fires (or where required by local building code), but not necessarily when exposure is only to a nuclear thermal pulse (which may well char the door without setting it on fire, a difficult thing to do to a flat wood wall).

Because this guide is intended for use by engineers and architects with special training in DCPA-conducted courses or their equivalent (as has been stated earlier[50] in a Preface and Chapter 1), technical competence in the usual design of wood structural members is assumed,[54-57] and only those design considerations peculiar to nuclear blast effects loading will be treated in some detail in this section.

Design Procedure. Because wood beams are available in specific dimensions, the general design approach is to select a trial member depth (measured in the direction of the applied load) and width, then find the air blast peak overpressure it can resist; this overpressure is compared

to the specified overpressure to be resisted. The resistance of the selected member is based on elasto-plastic behavior and associated stress resistances in flexure (bending), horizontal shear, and bearing on a support, which resistances are checked in that order. Specifically, the flexure and horizontal shear resistances are found, and then a new trial member is selected, repeating these steps until the lesser of the two resistances is found to be sufficient to meet the expected blast load. The required bearing area is then found directly.

The design steps are as follows:

1. A design air blast peak overpressure is specified, also whether its loading geometry will provide: a side-on overpressure (as in a wood door mounted flush with the earth's surface); a fully reflected overpressure (as in the front wall of a rectangular building); or a peak value of the average loading caused by a combination of side-on and drag pressure (as in the side-wall or roof of a rectangular building[1(§4.80-)]). Related variables, in the same order of loading geometries, look like this:

$$p_m = p_{so} \text{ or } p_r \text{ or } \left[(p_{so} + C_d q)\ L/2U\right] \tag{6-53}$$

where q is the dynamic (wind) blast pressure (unlike the q for structural resistance used in the remainder of this section).[1(p. 182-)]

2. A trial size of wood beam (actual depth *d*, measured in direction of load, and thickness or width b) and kind of structural or stress-graded lumber are selected, then the grading association's design stresses are determined from their publications. Need for the latter may be limited to F_b (extreme fiber stress in bending), F_v (horizontal shear stress), and $F_{c\perp}$ (compression stress perpendicular to grain, or bearing stress as used herein). For the short duration loadings furnished by nuclear air blast, dynamic values of the above three design stresses are recommended[23] as follows:

$$F_{db} = 4F_b \ ; \ F_{dv} = 4F_v \ ; \text{ and } F_{dc\perp} = F_{c\perp}$$

Some grading rules allow increases in design stress values for such things as: repetitive member design values (not recommended for use herein); and members used flatwise (probably appropriate for use herein).[52(p.130-1)]

3. A design ductility ratio μ is selected (see discussion in the earlier section herein, General Comments on Blast-Resistant Design . . .). A value of 3 is recommended,[23] certainly as an upper limit, and with 1.3 or 2 even better.[31]

4. A short design procedure[23] omits use of any loading decay (i.e., uses instead an instantaneously applied long duration load, or step pulse), load-mass factors, modulus of elasticity, elasto-plastic resistance function per se, etc., all in favor of the following approach: A step pulse is assumed, which is reasonable particularly when large yield weapons and short wood beams (therefore having very short periods of natural vibration) are considered.* The other things ignored have been found to have little effect on the structural member selected for most applications; and needed parameters then have the following relationship: $p_m/q = 1 - 1/(2\mu)$ where q is the ultimate resistance to blast loading of the wood beam. Using the recommended value of $\mu = 3$, the equation becomes: $p_m = (5/6)\ q$

5. Clear span L and support conditions are known or assumed. Formulas are included herein for three beam support conditions: simply supported (SS); propped cantilever (PC); and both ends fixed (FF).

6. Flexural or bending resistance q_b (in terms of load/unit area) is calculated for the trial member:

$$M = wL^2c = q_b bL^2c = F_{db}S = F_{db}bd^2/6$$

$$= F_{db}(d/L)^2/(6c) = 2F_b(d/L)^2/(3c) \qquad (6\text{-}54)$$

where c = 1/8 (SS) and (PC), 1/12 (FF).

7. Horizontal shear resistance q_v (in terms of load/unit area) is also calculated for the trial member, with horizontal shear equal to vertical shear and taken at a distance d in from each end of the member: member:[23(p.161),54(p.4-12)]

$$V = w(L-2d)c' = q_v b(L-2d)c' = 2AF_{dv}/3 = 2bdF_{dv}/3$$

$$q_v = 2F_{dv}d/(3c'(L-2d)) = 8F_v d/(3c'(L-2d)) \qquad (6\text{-}55)$$

where c' = 1/2 (SS) and (FF), 5/8 (PC), the latter value being approximate but close enough for the purposes herein.

8. Wood beam resistance q is then equal to the lesser value between q_b and q_v and is converted to peak air blast pressure by using a formula given earlier:

$$p_m = (1 - 1/(2\mu))\ q \qquad (6\text{-}56)$$

or, when the recommended value of $\mu = 3$ is used, $p_m = (5/6)\ q$.

---

* Alternatives to this use of a step pulse are chart solutions and the Newmark β Method, described herein (page 6-12, third paragraph).

9. If p_m is less than the design air blast peak overpressure specified in the first step herein, a larger beam, or a different wood or grade having larger design stresses, must be tried. If p_m is larger than the design overpressure, than it may be desirable to try a smaller beam, or a different wood or grade, in an effort toward closer design. In either case, a new trial member requires that the designer return to the second step and repeat the procedure to this point.

10. Required bearing length L' at each end of the wood beam is calculated as follows:

$$V = qbLc' = F_{c\perp}bL'$$

$$L' = qLc'/F_{c\perp} \tag{6-57}$$

where the values of c' are the same as in step 7 above.[55(p.206-7)] It is recommended that L' be at least 1.5 to 2 inches.

Application to a Shelter Door Design. An application of wood beam design occurs when low-cost blast doors must be designed for shelters, in new designs or existing structures. For an application in existing structures, particularly, a pre-design or chart approach was needed as follows:

- An estimate, calculated or judgmental, is made of the blast resistance of the wall adjacent to an aperture (door or window opening) for which a wood blast door is needed. The only designed structural element will be a wood beam, or series of wood beams side-by-side and preferably tongue-and-groove, simply supported on the two sides of the door frame (that has been either strengthened or found adequate to take the load from the door onto the wall).

- Structural grades of various kinds of wood, in standard thicknesses (2, 3, 4, 6 inches, nominal; 1.5, 2.5, 3.5, 5.5 inches, actual) are checked for availability.[52]

The pre-design or chart approach developed for simplified handling of this problem was as follows:

- Obtain a copy of the industry association grading rules for each kind of wood contemplated for possible use; from this, make a tabulation (for each kind of wood and each thickness) of design stresses (psi) stated for use under normal loading for:

- Bending design stress (in extreme fiber), F_b
- Horizontal shear design stress, F_v
- Compression perpendicular to grain design stress, $F_{c\perp}$

- Conversion of design stresses to dynamic values (step 2 above) is unnecessary hereunder; the charts used include this conversion and are therefore entered directly with the design stresses for normal loading.

- For each wood and thickness, determine the blast resistance in terms of free-field overpressure:
  - For the specific thickness, use the pre-design chart, Figure 6-11, which consists of four charts, covering member thicknesses of 1.5, 2.5, 3.5 and 5.5 in. The charts are based on use of Equations 6-53 through 6-56, and assume $\mu = 3$, step pulse and simple supports; the charts are entered with design, not dynamic, stresses (per the preceding paragraph).
  - Enter the chart with the known clear span: first, use the left set of curves, moving up to the known allowable design stress F_b for the selected wood, interpolating as necessary and noting the related applied overpressure (psi) read on the ordinate scale; second, repeat the procedure with the right set of curves (for stress in horizontal shear F_v), again noting the related overpressure. Use only the lower of the two applied overpressures read!

- For each wood and thickness still of interest, determine the required bearing length at each end of the wood beam:
  - Use the last wood pre-design chart, Figure 6-12. The chart is based on use of Equation 6-57, and assumes $\mu = 3$, step pulse and simple supports. Thus $L' = (6/5)\ p_m L\ (1/2) / F_{c\perp}$ (from Eq. 6-57); or $p_m = (5/3)\ L'F_{c\perp} / L$ for which Figure 6-12 is a plot for several specific values of $F_{c\perp}$ and L as the independent variable, all with $L' = 1$ in.
  - Enter with the clear span, move up to the allowed design stress, and read the applied overpressure on the ordinate scale; this applied overpressure is for one inch of bearing length on each end of the wood beam.

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FIG. 6-11A WOOD BEAM DESIGN, BENDING AND SHEAR

STRUCTURAL OR STRESS-GRADED LUMBER

Actual thickness 1.5 inches

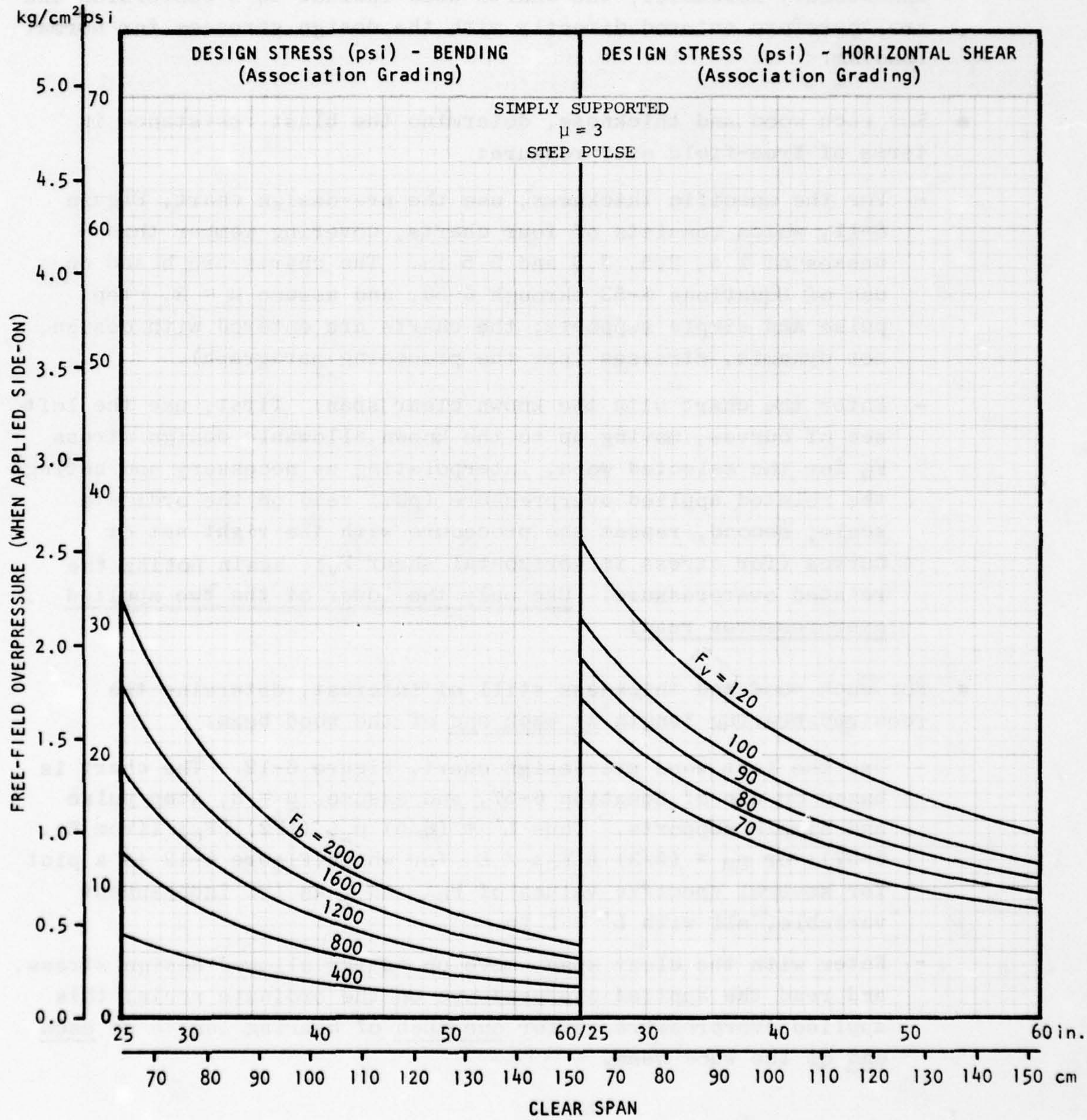

FIG. 6-11B WOOD BEAM DESIGN, BENDING AND SHEAR

STRUCTURAL OR STRESS-GRADED LUMBER
Actual thickness 2.5 inches

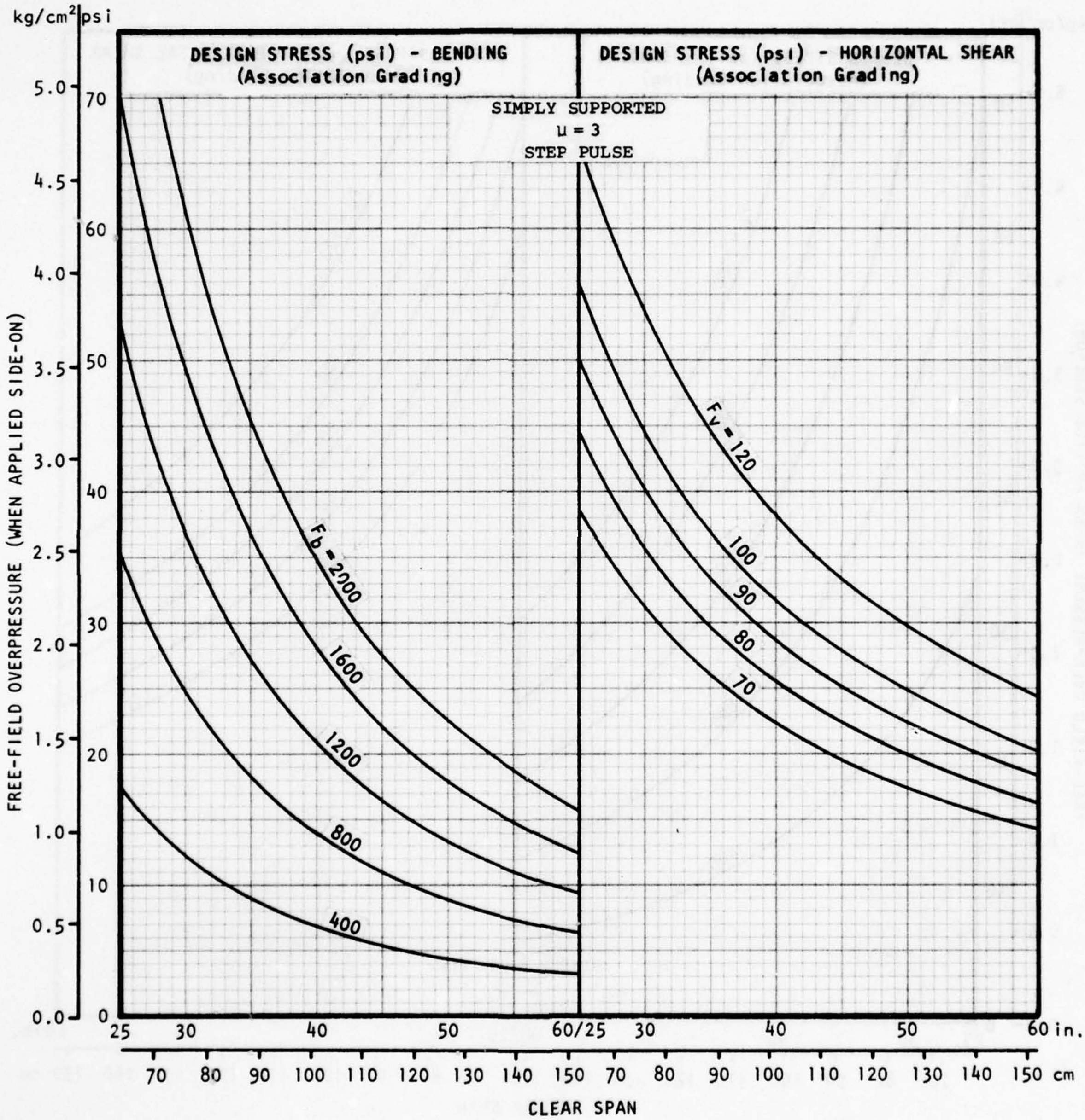

FIG. 6-11C WOOD BEAM DESIGN, BENDING AND SHEAR

STRUCTURAL OR STRESS-GRADED LUMBER
Actual thickness 3.5 inches

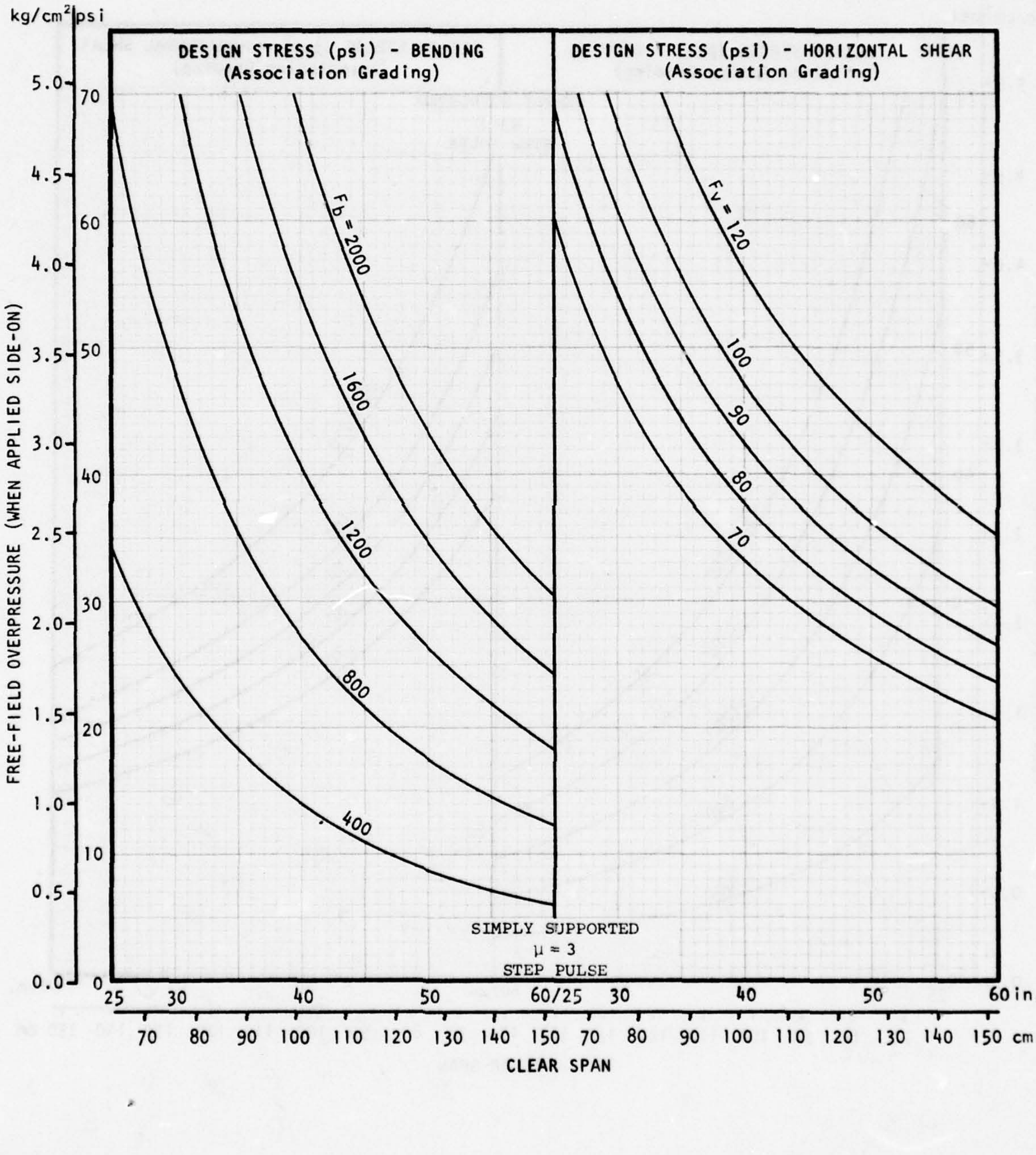

FIG. 6-11D WOOD BEAM DESIGN, BENDING AND SHEAR

STRUCTURAL OR STRESS-GRADED LUMBER
Actual thickness 5.5 inches

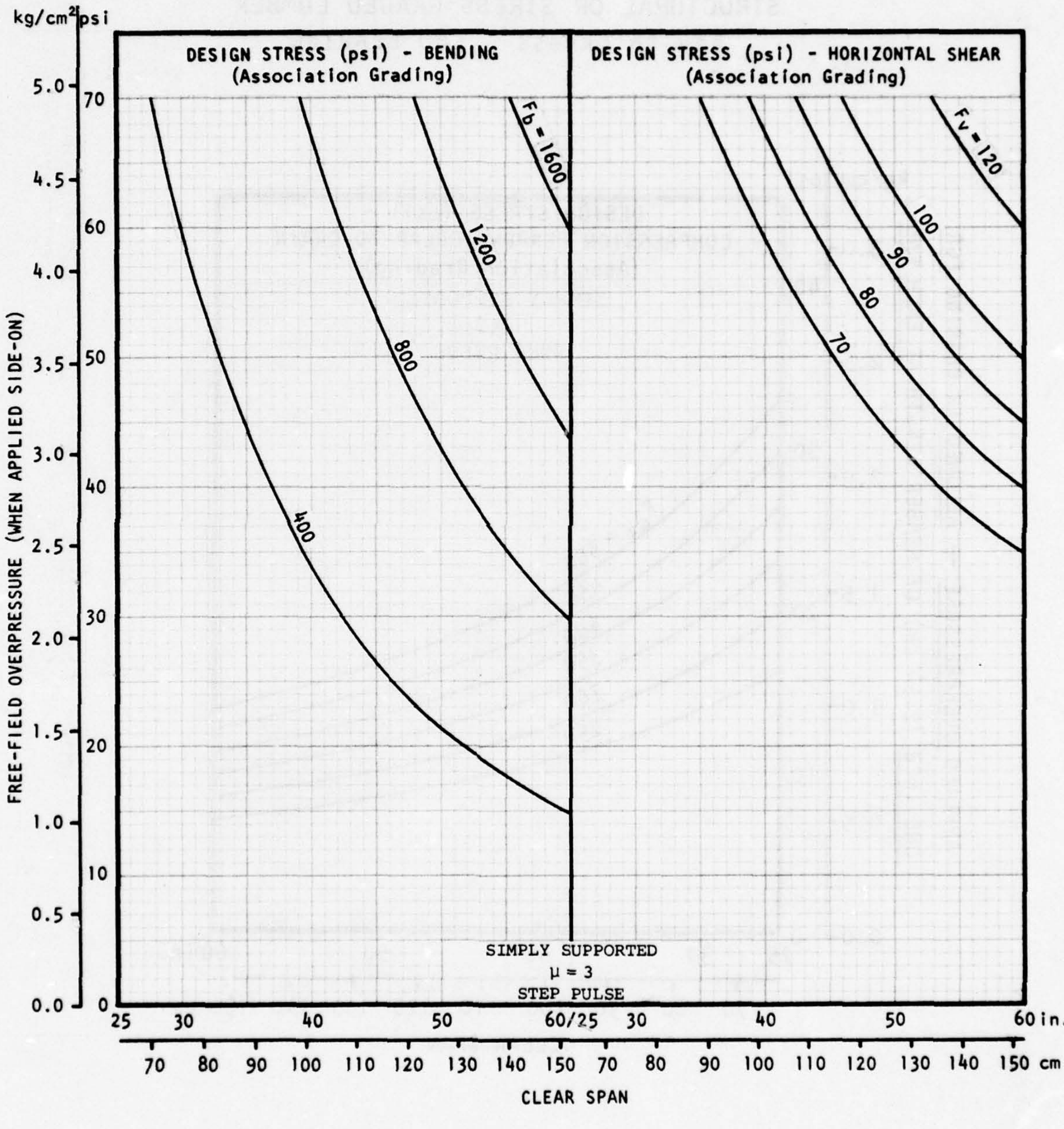

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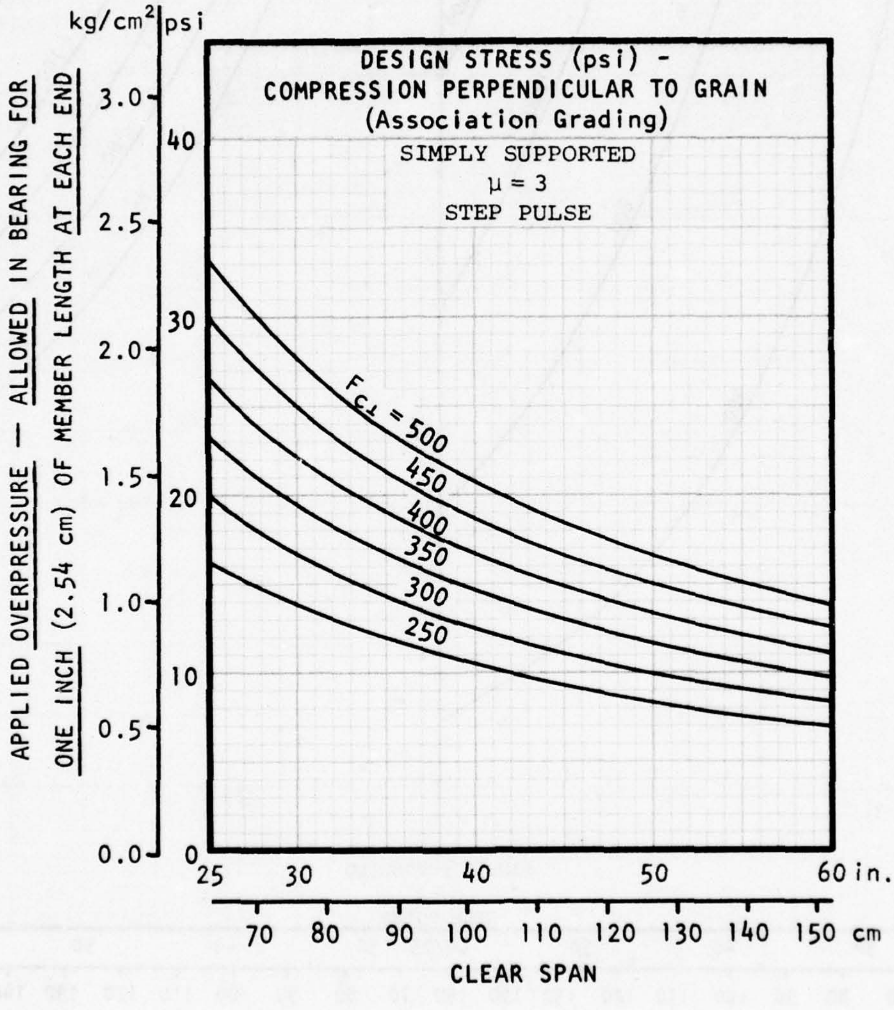
FIG. 6-12 WOOD BEAM DESIGN, END BEARING

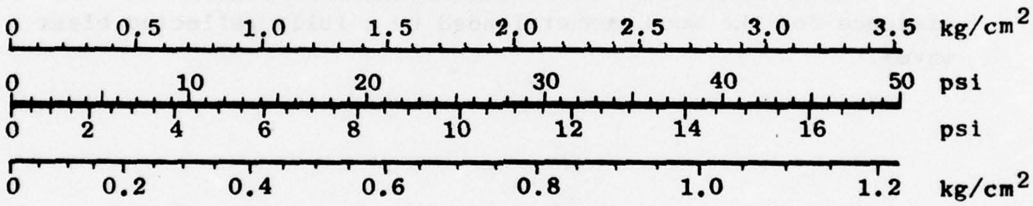
STRUCTURAL OR STRESS-GRADED LUMBER
Any thickness - END BEARING



- Divide this applied overpressure for bearing into the overpressure noted at the end of the preceding step (using Figure 6-11); the resulting quotient is the number of inches bearing length required at each end of the wood beam. It is recommended that a minimum length of, say, 1-1/2 or 2 inches be used.

- Applied overpressure, psi, determined above for the particular clear span and kind of wood (with its design stresses from the grading association), was the overpressure when applied side-on, such as if the wood beam were part of a cover or door, mounted flush with the ground and the blast wave passed over it flowing horizontally. If the member is to be used so that the blast wave strikes it head-on, as if the member were part of the front wall of a building struck by the blast wave, then the blast wave is fully reflected, making it equivalent in loading force to a much stronger wave applied only side-on. To relate these two situations by putting both in terms of free-field overpressure resistance (that is, out in the open, unaffected by structures), use the scales below:

FREE-FIELD OVERPRESSURE (WHEN APPLIED SIDE-ON)



FREE-FIELD OVERPRESSURE (WHEN APPLIED FULLY REFLECTED)

For example, a free-field overpressure of 45 psi hitting the member side-on gives the same peak loading to the member as a free-field overpressure of 16 psi hitting the member head-on, or fully reflected.

A numerical example of this procedure is as follows:

- Clear span 40 inches; bending design stress 1,250 psi; horizontal shear design stress 95 psi; compression perpendicular to grain design stress 385 psi. (These are the values for Douglas Fir, #2 Grade, under Structural Joists and Planks, Table 6.)[52] Assumed blast orientation is head-on, or fully reflected.

---

* Assuming ambient air pressure (ahead of blast shock front) of 14.7 psi; see Eq. 3.50.2, Ref. 1 (p. 123).

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- First thickness of above wood to be checked for blast resistance is 3 in. nominal, 2.5 in. actual. Entering the chart, Figure 6-11B, for that thickness, clear span 40 in.: design stress in bending of 1,250 psi gives about 21 psi overpressure; design stress in horizontal shear of 95 psi gives about 30 psi overpressure.

- Required bearing length at each end of the wood beam is obtained by using the last chart, Figure 6-12: entering with a clear span of 40 in., and interpolating for a design stress of 385, gives an applied overpressure (per inch of bearing at each end) of about 16 psi. Dividing the 16 psi. Dividing the 16 psi into the 21 psi noted just above gives a member length at each end, for bearing, of $\frac{21}{16}$ or 1-5/16 in. for which the used length would be rounded (upward ALWAYS) to, say, 1.5 in. at each end (which is a minimum recommended above).

- Free-field overpressure applied head-on, i.e., fully reflected, is found by entering the scale above with the 21 psi side-on (free-field overpressure resistance) and finding this numerical example's answer of about 8.5 psi (free-field overpressure resistance for the wood member loaded by a fully reflected blast wave).

Appendix B

REFERENCES

1. Glasstone, S. editor, The Effects of Nuclear Weapons, U.S. Department of Defense and Atomic Energy Commission, February 1964 reprint (with changes) of 1962 edition, Superintendent of Documents, Washington, D.C. 20402.

23. Newmark, N. M., Design of Openings for Buried Shelters, Report 2-67, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., July 1963.

31. Discussions with project consultant, Professor W. J. Hall, University of Illinois.

50. Murphy, H. L., Feasibility Study of Slanting for Combined Nuclear Weapons Effects (Revised), Stanford Research Institute Technical Report, for U.S. Office of Civil Defense (now Defense Civil Preparedness Agency), 2 vols., July 1971. (AD-734 831 and 2)*

52. Standard Grading Rules for West Coast Lumber, West Coast Lumber Inspection Bureau, Portland, Oregon, No. 16, Revised January 1, 1973 ($1).

53. 1970 Standard Grading Rules for Southern Pine Lumber, Southern Pine Inspection Bureau, Pensacola, Florida, including Supplements #1 and #2.

54. Timber Construction Manual, American Institute of Timber Construction, Washington, D.C., 1st ed., 1966 (Wiley); 2nd ed., 1974 is available.

55. Wood Handbook, Forest Products Laboratory, Forest Service, U.S. Department of Agriculture, Handbook No. 72, 1955; new edition is available, Revised August 1974, through the Supt. of Documents, Washington, D.C. 20402.

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* Those references for which "AD-" numbers are shown are understood to be available for purchase from NTIS, Springfield, Virginia, 22151.

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56. Gaylord, E. H. Jr., and C. N. Gaylord, editors, Structural Engineering Handbook, 1968, (McGraw-Hill); Section 16.

57. Merritt, F. S., editor, Standard Handbook for Civil Engineers, 1968 (McGraw-Hill); Section 11.

ADDENDUM

Besides its use as a reference source for Appendix A, this Addendum and Appendix B may be used to develop simplified charts for use of "2-by" materials,* in plentiful supply in local lumberyards, as closures over apertures in basements having a good potential for upgrading into shelter against the combined effects of a nuclear weapon detonation.

Appendix B, Design Step 2, is supplemented by the following: Use of L/d values less than five (5) is not recommended because of doubt that the design procedure covers wood "deep beams."

Using the same materials as in the lower and higher strength stringers of Appendix A1 leads to the following design stresses in normal-use design:[1]

	F_b	F_v	$F_{c\perp}$	
Lower strength members	450 psi	70 psi	235 psi	2x3s and 2x4s
	975	70	235	2x6s and 2x8s
Higher strength members	1200	95	385	2x3s and 2x4s
	1750	95	385	2x6s and 2x8s

It is assumed that the "2-by" materials used for closures will be held together by nailed-cleated cross members on at least one side, preferably two, so that these normal-use allowable stresses that are for repetitive-member uses, will be appropriate for use herein.

Translation of the above stresses into air blast dynamic values, and an assumed value for the ductility ratio μ follow from design steps 2 and 3 of the basic appendix (F_b and F_v increased by a factor of 4, and $\mu = 3$ used).

---

* Actually, these (construction grade) wood members could be any width, not just "2-by", and, except for "2-by's used flatwise", Figures B-1 would still apply to the member depths shown (3, 4, 6 and 8 inches).

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A computer program using the design procedure in the basic appendix was repeatedly used to develop designs that in turn led to Figures B-1* that follow; for "2-by" members used flatwise, the above values for F_b were increased by a factor of 1.1, which is that for 2" thick material, 2" to 4" wide, under the grading rules.[1] Listings of three computer programs are in Table B-1.

NOTE: It is regretted that "2-by's" was ever used herein and in Figures B-1A and B, even though 2-by materials are very commonly available. The thickness of the closure material measured perpendicular to the blast wave flow direction is important. The other (width) dimension of the stress-graded wood members used is unnecessary to the use of Figures B-1; however, there is one refinement that might be applied to one curve of each, Figures B-1A and B: In the "2-by flatwise" curve, only 2x2s, plus 2x3s and 2x4s used flatwise, can be used directly with it. The curve can be used, however, for 2x6s and 2x8s flatwise by simply increasing the overpressure values read by 11%.

---

* Normal use allowable stresses are shown, but blast dynamic values were used in calculations for the graph curves.

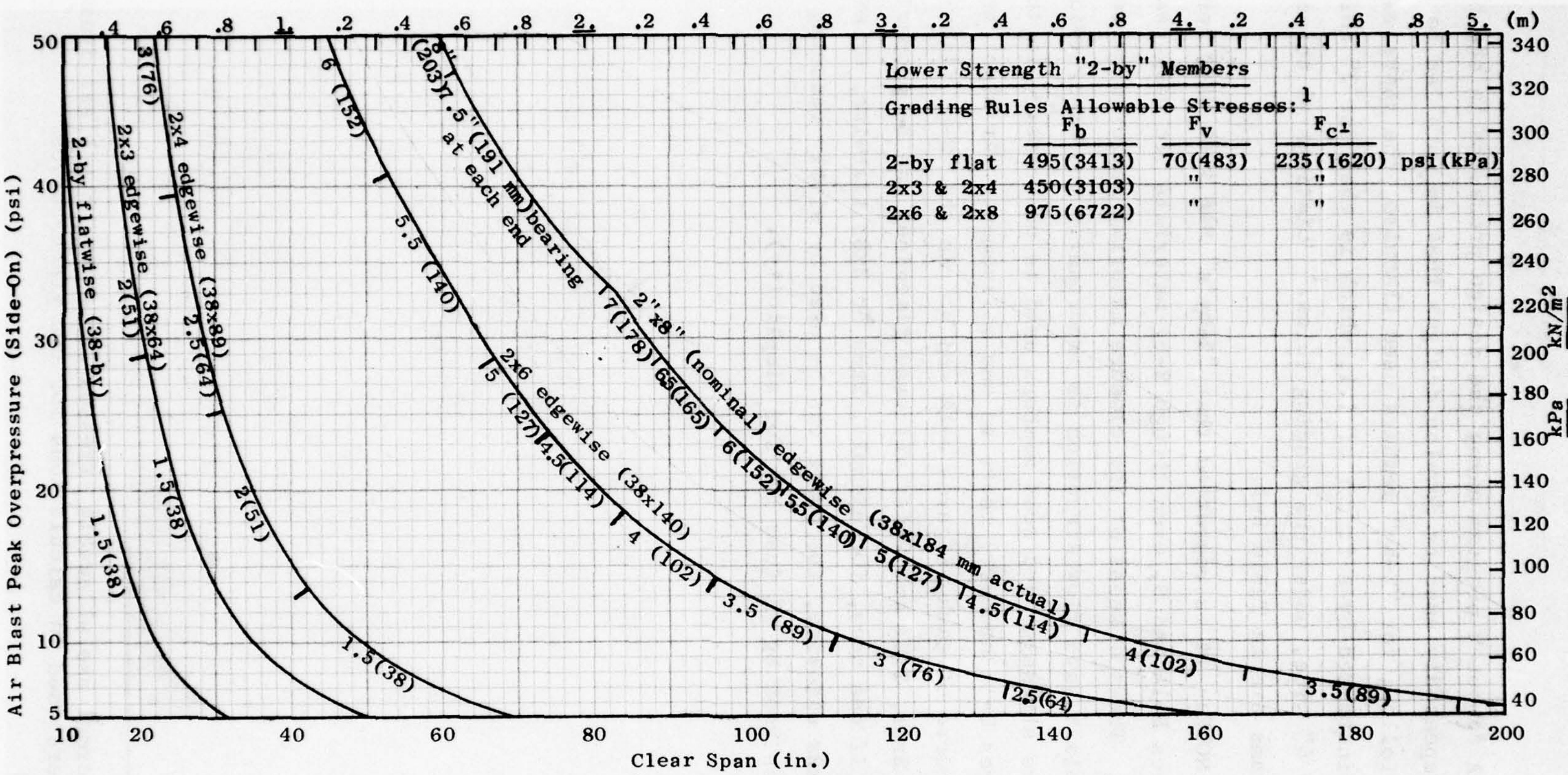

FIGURE B-1A DESIGNS OF CLOSURES USING "2-BY" MEMBERS

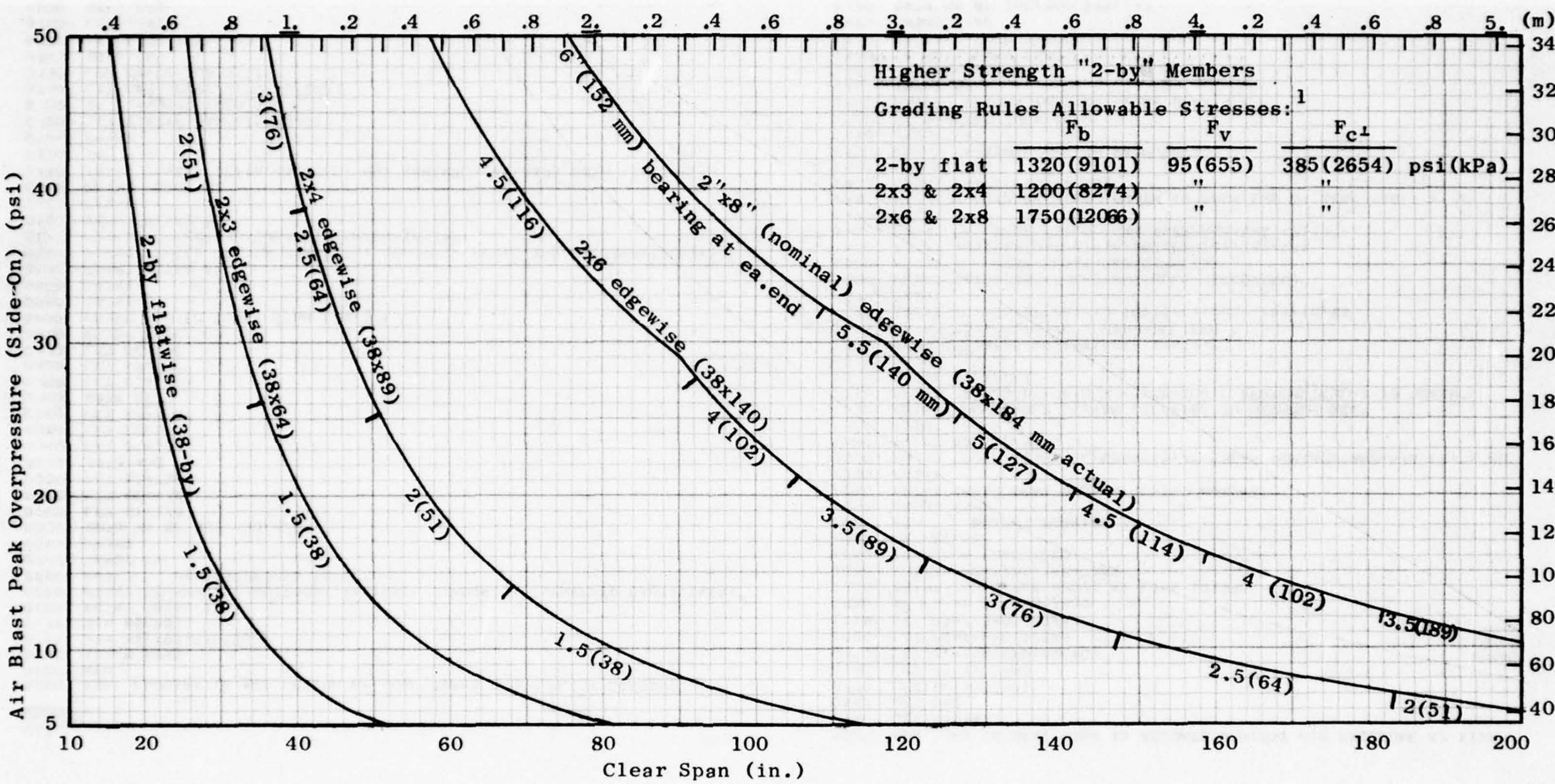

FIGURE B-1B DESIGNS OF CLOSURES USING "2-BY" MEMBERS

Table B-1 LISTING OF COMPUTER PROGRAMS (HLMWBM, HMWBM1 & 2)

```
LIS
HLMWBM

0100 REM  PROGRAM IS FOR DESIGN OF WOOD BEAMS UNDER BLAST LOADING
0120 REM
0140 GOSUB 1740
0160 DIM N$[10],A$[10]
0170 DIM B$[20]
0180 PRINT "STEP 1"
0200 PRINT "SUPPORT CONDITION: 1=SIMPLE SUPPORTS; 2=PROPPED CANTILEVER;"
0220 PRINT "  3=FIXED-FIXED ENDS";
0240 INPUT N9
0260 PRINT
0280 GOTO N9 OF 300,360,420
0300 LET C1=1/8
0320 LET C2=1/2
0330 LET A$="SS"
0340 GOTO 460
0360 LET C1=1/8
0380 LET C2=5/8
0390 LET A$="PC"
0400 GOTO 460
0420 LET C1=1/12
0430 LET A$="FF"
0440 LET C2=1/2
0460 PRINT "STEP 2"
0480 PRINT "ENTER CLEAR SPAN (IN.)";
0500 INPUT L
0520 PRINT
0540 PRINT "STEP 3"
0560 PRINT "ENTER DESIGN STRESSES: BENDING, HORIZ.SHEAR, COMPRESSION"
0580 PRINT "  PERPENDICULAR TO GRAIN (PSI)";
0600 INPUT F1,F2,F3
0620 PRINT
0640 PRINT "STEP 4"
0660 PRINT "ENTER DEPTH (ACTUAL, NOT NOMINAL) OF WOOD BEAM (IN.)";
0680 INPUT D
0700 PRINT
0720 LET Q1=2*F1*(D/L)↑2/3/C1
0730 IF L <= 2*D THEN 750
0740 LET Q2=8*F2*D/3/C2/(L-2*D)
0750 LET B$="Q-SUB B(Q1)"
0755 GOTO 780
0760 IF Q1>Q2 THEN 820
0780 LET Q=Q1
0800 GOTO 840
0820 LET Q=Q2
0830 LET B$="Q-SUB V(Q2)"
0840 LET L1=Q*L*C2/F3
0860 REM    U IN NEXT LINE IS MU, DUCTILITY RATIO
0880 LET U=3
0900 LET P1=Q*(1-1/(2*U))
0920 REM   P3 IN NEXT LINE IS ASSUMED AMBIENT AIR PRESSURE AT SITE
0940 LET P3=14.7
0960 LET A=8
0970 LET B=14*P3-P1
0980 LET C=-7*P1*P3
0990 LET D1=SQR(B*B-4*A*C)
1000 LET P2=(-B+D1)/2/A
1010 LET P5=(-B-D1)/2/A
1020 IF P5 <= 0 THEN 1220
1030 PRINT "MULTIPLE ROOTS AT LINE 1010"
1040 PRINT "P2=";P2,"P5=";P5
1050 IF P2<P5 THEN 1220
1060 LET P2=P5
1220 REM     OUTPUT PORTION
1240 GOSUB 1740
1260 PRINT "WOOD BEAM DESIGN (USING MU=3):"
1280 PRINT
1300 PRINT "SUPPORTS","CL.SPAN(IN.)","BEAM DEPTH","AMB.AIR PR.","MU"
1340 PRINT A$,L,D,P3,U
1360 PRINT
1362 PRINT "ALLOWABLE DESIGN STRESSES IN NORMAL-USE:"
1364 PRINT "F-SUB B","F-SUB V","F-SUB C PERPENDICULAR TO GRAIN"
1370 PRINT F1,F2,F3
1371 PRINT
1373 PRINT "STATIC RESISTANCES (PSI):"
1375 PRINT "Q","(5/6) Q","CONTROLLING"
1377 PRINT INT(10*Q+1/2)/10,INT(5/6*10*Q+1/2)/10,B$
1379 PRINT
1380 PRINT "SIDE-ON","HEAD-ON(FULLY REFLECTED)";
1390 PRINT "   PEAK BLAST RESISTANCES"
1400 PRINT INT(P1*10+1/2)/10,INT(P2*10+1/2)/10;
1420 PRINT "AS FREE-FIELD PEAK OVERPRESSURE (PSI)"
1440 PRINT
1460 PRINT "REQ'D BEARING LENGTH AT EACH END OF BEAM (IN.) = ";
1480 PRINT INT(L1*10+1)/10
1500 GOSUB 1740
1520 PRINT "ANOTHER DESIGN PROBLEM";
1540 INPUT N$
1560 IF N$="NO" THEN 1820
1580 PRINT "RETURN TO STEP 1, 2, 3 OR 4";
1600 INPUT N8
1620 LET N8=INT(N8)
1640 IF N8<1 THEN 1580
1660 IF N8>4 THEN 1580
1680 GOSUB 1740
1700 GOTO N8 OF 180,460,540,640
1720 STOP
1740  FOR I=1 TO 5
1760  PRINT
1780  NEXT I
1800 RETURN
1820 END
```

Table B-1 (continued)

```
RUN
HLMWBM


STEP 1
SUPPØRT CØNDITIØN: 1=SIMPLE SUPPØRTS; 2=PRØPPED CANTILEVER;
  3=FIXED-FIXED ENDS?1

STEP 2
ENTER CLEAR SPAN (IN.)?60

STEP 3
ENTER DESIGN STRESSES: BENDING, HØRIZ.SHEAR, CØMPRESSIØN
  PERPENDICULAR TØ GRAIN (PSI)?2000,100,400

STEP 4
ENTER DEPTH (ACTUAL, NØT NØMINAL) ØF WØØD BEAM (IN.)?3.5



WØØD BEAM DESIGN (USING MU=3):

SUPPØRTS        CL.SPAN(IN.)    BEAM DEPTH      AMB.AIR PR.     MU
SS              60              3.5             14.7            3

ALLØWABLE DESIGN STRESSES IN NØRMAL-USE:
F-SUB B         F-SUB V         F-SUB C PERPENDICULAR TØ GRAIN
 2000            100             400

STATIC RESISTANCES (PSI):
Q               (5/6) Q         CØNTRØLLING
 36.3            30.2           Q-SUB B(Q1)

SIDE-ØN         HEAD-ØN(FULLY REFLECTED)    PEAK BLAST RESISTANCES
 30.2            11.6         AS FREE-FIELD PEAK ØVERPRESSURE (PSI)

REQ'D BEARING LENGTH AT EACH END ØF BEAM (IN.) = 2.8


ANØTHER DESIGN PRØBLEM?NØ
```

```
LIS
HMWBM1

0100  REM  PRØGRAM IS FØR DESIGN ØF WØØD BEAMS UNDER BLAST LØADING
0110  REM    THIS MØDIFICATIØN ØF HLMWBM ALLØWS MULTIPLE RUNS BUT
0112  REM     ØMITS CALCULATIØN ØF P-SUB R BEAM RESISTANCE IN TERMS
0114  REM     ØF PEAK FREE-FIELD AIR BLAST LØADING
0120  REM
0140  GØSUB 1740
0160  DIM N$(10),A$(40)
0170  GØSUB 560
0172  GØSUB 1740
0174  PRINT "CL.SPAN(IN).","P-SUB DM(PSI)","L1 EA.END(IN.)"
0176  PRINT
0300  LET C1=1/8
0320  LET C2=1/2
0330  LET A$="SS"
0335  GØTØ 710
0560  PRINT "ENTER DESIGN STRESSES: BENDING, HØRIZ.SHEAR, CØMPRESSIØN"
0580  PRINT "  PERPENDICULAR TØ GRAIN (PSI)";
0600  INPUT F1,F2,F3
0620  PRINT
0660  PRINT "ENTER DEPTH (ACTUAL, NØT NØMINAL) ØF WØØD BEAM (IN.)";
0680  INPUT D
0700  PRINT
0702  RETURN
0710   FØR L=10 TØ 200 STEP 10
0720   LET Q1=2*F1*(D/L)↑2/3/C1
0730   IF L <= 2*D THEN 780
0740   LET Q2=8*F2*D/3/C2/(L-2*D)
0760   IF Q1>Q2 THEN 820
0780   LET Q=Q1
0800   GØTØ 840
0820   LET Q=Q2
0840   LET L1=Q*L*C2/F3
0860   REM   U IN NEXT LINE IS MU, DUCTILITY RATIØ
0880   LET U=3
0900   LET P1=Q*(1-1/(2*U))
1070   REM     ØUTPUT PØRTIØN
1080   IF P1>70 THEN 1190
1090   PRINT L,INT(10*P1+1/2)/10,INT(10*L1+1)/10
1100   PRINT
1110   IF P1<5 THEN 1710
1190   NEXT L
1710  GØSUB 1740
1720  GØTØ 170
1740   FØR I=1 TØ 5
1760   PRINT
1780   NEXT I
1800  RETURN
1820  END
```


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Table B-1 (concluded)

```
RUN
HMWBM1


ENTER DESIGN STRESSES: BENDING, HØRIZ.SHEAR, CØMPRESSIØN
  PERPENDICULAR TØ GRAIN (PSI)?495,70,235

ENTER DEPTH (ACTUAL, NØT NØMINAL) ØF WØØD BEAM (IN.)?1.5


CL.SPAN(IN).   P-SUB DM(PSI)   L1 EA.END(IN.)

 10            49.5            1.3

 20            12.4            .7

 30            5.5             .5

 40            3.1             .4


LIS
HMWBM2

0100  REM  PRØGRAM IS FØR DESIGN ØF WØØD BEAMS UNDER BLAST LØADING
0110  REM     THIS MØDIFICATIØN ØF HMWBM1 (A MØDIFICATIØN ØF HLMWBM)
0112  REM     CALCULATES THE LØCATIØN ØN THE CURVES RESULTING FRØM
0114  REM     HMWBM1 CALC'S WHERE SPECIFIC END BEARING VALUES (E.G.,
0116  REM     1.5 IN.) APPLY AND CAN BE SHØWN AS TIC MARKS
```

```
0120 REM
0140 GØSUB 1740
0160 DIM N$[10],A$[10]
0170 GØSUB 560
0172 GØSUB 1740
0176 PRINT
0180 LET N1=0
0300 LET C1=1/8
0320 LET C2=1/2
0330 LET A$="SS"
0335 GØTØ 710
0560 PRINT "ENTER DESIGN STRESSES: BENDING, HØRIZ.SHEAR, CØMPRESSIØN"
0580 PRINT "  PERPENDICULAR TØ GRAIN (PSI)";
0600 INPUT F1,F2,F3
0620 PRINT
0660 PRINT "ENTER DEPTH (ACTUAL, NØT NØMINAL) ØF WØØD BEAM (IN.)";
0680 INPUT D
0700 PRINT
0702 RETURN
0710 PRINT "FØR D =   ";D
0712 PRINT "L1","L","P1"
0713 PRINT
0715  FØR L1=6.5 TØ 1.5 STEP -.5
0716  LET A=0
0717  LET B=1000
0718  LET C=.5*(B-A)
0719  LET L=A+C
0720  LET Q1=2*F1*(D/L)^2/3/C1
0725  LET N1=N1+1
0726  IF N1=100 THEN 1715
0730  IF L <= 2*D THEN 780
0740  LET Q2=8*F2*D/3/C2/(L-2*D)
0760  IF Q1>Q2 THEN 820
0780  LET Q=Q1
0800  GØTØ 830
0820  LET Q=Q2
0830  LET Q9=L1*F3/L/C2
0835  IF ABS(Q-Q9) <= .01 THEN 880
0840  IF Q>Q9 THEN 855
0845  LET B=A+C
0850  GØTØ 860
0855  LET A=A+C
0860  LET C=.5*(B-A)
0865  GØTØ 719
0880  LET U=3
0900  LET P1=Q*(1-1/(2*U))
1070  REM    ØUTPUT PØRTIØN
1090  PRINT L1,INT(L+1/2),INT(10*P1+1/2)/10
1100  PRINT
1110  LET N1=0
1190  NEXT L1
1710 GØSUB 1740
1714 IF N1<100 THEN 1720
1715 PRINT "N1=  ";N1;"   IN LINE 725"
1720 GØTØ 140
1740  FØR I=1 TØ 5
1760  PRINT
1780  NEXT I
1800 RETURN
1820 END
```

NOTATION

A	area of beam cross-section
b	width of beam
C_d	drag coefficient (= ratio of drag pressure on object to dynamic/wind pressure in free field)
c, c'	dimensionless coefficients
d	depth of wood beam
F_b	extreme fiber stress in bending
F_{db}	dynamic F_b
$F_{c\perp}$	compression stress perpendicular to grain, or bearing stress
$F_{dc\perp}$	dynamic $F_{c\perp}$
F_v	horizontal shear stress (in wood)
F_{dv}	dynamic F_v
L	span length of member (clear span unless otherwise indicated)
L'	bearing length at each end of wood beam
M	bending moment
p_m	peak (unit) value of applied (air blast) loading
p_r	peak reflected (air blast) overpressure
p_{so}	peak side-on (air blast) overpressure
q	resistance of member, ultimate
q_b	bending q
q_v	horizontal shear q
S	section modulus
U	shock velocity (air blast)
V	vertical shear
w	load per unit length of beam
μ	ductility ratio (of maximum deflection to yield deflection)

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REFERENCE

1. National Design Specification for Stress-Grade Lumber and Its Fastenings, National Forest Products Association, 1619 Massachusetts Avenue, N.W., Washington, D.C., 20036, 1973 edition, with Table 1 Supplement (allowable unit stresses, published separately), April 1973, revised November 1974.

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Appendix C

TYPICAL STOCKAGE - LOCAL LUMBERYARDS

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CONTENTS

TABLES

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Introduction

The most convenient source of blocking and strengthening materials for expedient blast upgrading will ordinarily be the local lumber-building materials yards catering to the "do-it-yourselfer" and small building contractors. These yards are usually supplied from wholesale yards which supply the smaller yards and also cater directly to the larger building contractors. The wholesale yards (and some of the larger local yards and larger building contractors) are supplied on a truck or carload basis direct from mills or through jobbers.

The inventory or stockage carried by the local yards will vary quite widely in both type and quantity of materials, depending on volume of business, local construction practices, etc. The following may be considered as typical, however, of available types, sizes and grades for lumber and plywood. Typical stockages for fastenings and other pertinent materials are also indicated.

Lumber

A. Grades and Species

Lumber grade classifications include the appearance grades, stress grades and construction grades. The appearance grades are ordinarily limited to 1" nominal thicknesses and are not considered applicable to expedient protection. The stress grades are used for heavy engineered structures and are not considered applicable for expedient protection; further, they are generally not stocked in local yards. Their use in fully engineered upgrading and predesigned expedient upgrading is applicable, however, as discussed in other parts of this report. The construction grades are the most widely stocked in local yards and are also the most applicable to expedient upgrading.

In terms of nominal, not actual, dimensions, the construction grades are divided into Boards (1" to 1½" thick, 2" and wider), Dimension Lumber (2" to 4" thick, any width), and Timbers (5" thick and thicker, 5" wide and wider). Dimension lumber is further subdivided into Light Framing

(2" to 4" thick, 2" to 4" wide), Joists and Planks (2" to 4" thick, 6" and wider), and Decking (2" to 4" thick, 6" wide). Timbers are further subdivided into Beams and Stringers (5" and thicker width more than 2" greater than thickness), and Posts and Timbers (5" by 5" and larger, width not more than 2" greater than thickness).

Within the above subdivisions, grade nomenclature and allowable stresses are established by trade associations, based on species.* The associations and the species covered are:

1. West Coast Lumber Inspection Bureau (WCLIB) - Douglas Fir, Western Hemlock, White Fir, and other minor species.

2. Western Wood Products Association (WWPA) - Douglas Fir, Western Hemlock, True (White) Firs, Western Pines (Ponderosa, Sugar, Lodgepole, and Idaho (Western) White Pine), and Larch.

3. Southern Pine Inspection Bureau (SPIB) - Southern Pine (Longleaf, Slash, Shortleaf, Loblolly), and other minor pine species (Virginia, Pond, Pitch).

4. Northeastern Lumber Manufacturers Association (NELMA) - Eastern White Pine, Northern (White) Pine, Norway Pine, Eastern Hemlock, and other minor species.

5. Northern Hardwood & Pine Manufacturers Association (NHPMA) - Eastern White Pine, Northern (White) Pine, Norway (Red) Pine, Eastern Hemlock, and other minor species.

The minor species identified in the above include various types of cedar, spruce, cypress, aspen, redwood and others not considered useful for blast upgrading purposes.

For usual engineering design purposes, dimension lumber and timbers are given allowable stresses according to grade and species. The construction grades are visually graded following the rules of the trade

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* Grading rules of the associations conform to Voluntary Product Standard 20-70, American Softwood Lumber Standard, U.S. Department of Commerce.

associations listed. Table 1 lists nomenclature, sizes, grades and typical allowable stresses for the most numerous species manufactured in the United States.

B. Typical Lumber Stocks

A typical local lumberyard will by no means stock all of the sizes and grades listed in Table 1A. Further, the allowable unit stresses in bending (usual design)* are provided simply as indicators of relative strength; other allowable stresses, and all stresses increased for blast-resistant design, are needed in use, as discussed in the plywood stressed-skin panel design procedure in Appendix A1. Stockages of dimension lumber useful for expedient blast protection purposes will generally be limited to those materials used for residential construction purposes by small contractors. Table 1B shows only the highly available materials selected for use in Appendices A and B (Addendum), and shows other-than-bending allowable stresses (normal use).

The stockages listed in Table 2 may be taken as typical.

Plywood

C. Classification

Plywood is classed as to type, species and grades. Classification is based on the United States Product Standards for Construction and Industrial Plywood, PS 1-74, U.S. Department of Commerce.

1. Type - Plywood is manufactured in Interior and Exterior types depending on intended use. Exterior type plywood is made with fully waterproof glue and in addition has a restriction that no veneer grade below C may be used. Some plywood is also manufactured as "Interior Plywood with Exterior Glue."

2. Species - The various species of wood from which plywood is manufactured are divided into five groups. Only four of these groups

---

* Table 1 values are based on "repetitive member use" and 19% maximum moisture content.[11(Table 1)]

Table 1A

SELECTED DIMENSION LUMBER SPECIES, SIZES AND GRADES(1)
(CONSTRUCTION GRADES)

Size and Grade(3)	Douglas Fir and Larch (WCLIB-WWPA)	Western Hemlock & White Fir (WCLIB-WWPA)	Western Pines (4) (WWPA)	Southern Pine (SPIB)	Northern Pine (NELMA-NHPMA)
	Species and Grading Agency(2)				
	Allowable Unit Stress (for usual design), psi, Extreme Fiber in Bending (F_b)(5)				
Structural Light Framing (2" to 4" thick, 2" to 4" wide)					
Select Structural	2400	1900	1650	2400	1850
No. 1	2050	1600	1400	2000	1600
No. 2	1650	1350	1150	1450	1300
No. 3	925	725	625	950	725
Stud	925	725	625	950	725
Light Framing (2" to 4" thick, 4" wide)					
Construction	1200	975	825	1200	950
Standard(6)	675	550	450	700	525
Utility	325	250	225	325	250
Joists and Planks (2" to 4" thick, 6" and wider)					
Select Structural	2050	1650	1400	2050	1600
No. 1	1750	1400	1200	1750	1400
No. 2	1450	1150	975	1200	1100
No. 3	850	675	575	825	650
Decking (Tongue and Groove (2" to 4" thick, 6" and wider)					
Select(7)	2000	1600	1350	2000	1550
Commercial(8)	1650	1300	1150	1650	1300
Beams and Stringers(9) (5" and thicker, width more than 2" greater than thickness)					
Select Structural(10)	1600	1300	1100	1500	1250
No. 1(11)	1300	1050	925	1300	1050
Posts and Timbers(9) (5"x5" and larger, width not more than 2" greater than thickness)					
Select Structural(10)	1500	1200	1000	1500	1150
No. 1(11)	1200	950	825	1300	950

Table 1B

SELECTED DIMENSION LUMBER SPECIES, SIZES AND GRADES[1]
(CONSTRUCTION GRADES)

Size and Grade[3]		Douglas Fir and Larch	Western Hemlock	Ponderosa, Sugar and Lodgepole Pines	Southern Pine	Northern Pine
		Allowable Unit Stresses in Normal Use, psi* (Ref. 11)				
Light Framing						
(2" to 4" th., 4" wide)						
Construction	F_b	1200	1050	825	1200	950
	F_v	95	90	70	75	70
	$F_{c\perp}$	385	280	235	345	280
	E (x 10^6)	1.5	1.3	1.0	1.4	1.1
Standard(6)	F_b	675	600	450	700	525
	F_v	95	90	70	75	70
	$F_{c\perp}$	385	280	235	345	280
	E	1.5	1.3	1.0	1.4	1.1
Joists and Planks						
(2" to 4" th., 6" and wider)						
Select Structural						
No. 1	F_b	1750	1550	1200	1750	1400
	F_v	95	90	70	90	70
	$F_{c\perp}$	385	280	235	405	280
	E	1.8	1.6	1.2	1.8	1.4
No. 2	F_b	1450	1250	975	1200	1100
	F_v	95	90	70	75	70
	$F_{c\perp}$	385	280	235	345	280
	E	1.7	1.4	1.1	1.4	1.3

* Notation used is: F_b is for extreme fiber in bending (repetitive member use); F_v is for horizontal shear; $F_{c\perp}$ is for compression perpendicular to grain; and E is for modulus of elasticity. In dynamic uses herein, F_b and F_v are multiplied by four, as explained in the appendices where these tabulated stresses are used.

Notes to Table 1

(1) Includes visually stress graded lumber only.
(2) WCLIB - West Coast Lumber Inspection Bureau
WWPA - Western Wood Products Association
SPIB - Southern Pine Inspection Bureau
NELMA - Northeastern Lumber Manufacturers Association
NHPMA - Northern Hardwood and Pine Manufacturers Association
(3) Nominal sizes; see references for dressed sizes.
(4) Includes Ponderosa, Lodgepole and Sugar Pine (averaged).
(5) Given for comparative purposes only. See references and other sections of this report for values to use for blast upgrading design. Beams/Stringers and Posts/Timbers values are based on single member use, all others on repetitive member use. 19% moisture content is assumed for all grades and sizes.
(6) Also graded as "Standard and Better."
(7) Dense Std. Factory for Southern Pine.
(8) No. 1 Dense Factory for Southern Pine.
(9) Ordinarily unsurfaced.
(10) No. 1 Dense Structural for Southern Pine.
(11) No. 1 Structural for Southern Pine.

References Used for Table 1

1. Uniform Building Code, 1976, Table 25-A-1.
2. Uniform Building Code Standards, 1976, Standards 25-1 through 25-8.
3. Standard Grading Rules, West Coast Lumber Inspection Bureau, 1975.
4. Standard Grading Rules, Western Wood Products Assn., 1974.
5. Standard Grading Rules, Southern Pine Inspection Bureau, 1970, plus Supplements to 1976.
6. Standard Grading Rules, Northeastern Lumber Manufacturers Assn., 1974, plus 1975 Supplement.
7. Standard Grading Rules, Northern Hardwood and Pine Manufacturers Assn., 1970.
8. Voluntary Product Standard 20-70, American Softwood Lumber Standard, U.S. Department of Commerce.
9. Wood Handbook, Forest Service Agriculture Handbook No. 72, 1974.
10. Douglas Fir Use Book, West Coast Lumbermans Assn.
11. National Design Specifications for Stress Graded Lumber and Its Fastenings, National Forest Products Assn., 1973 ed. (Table 1, Nov. 1974).

NOTE: Allowable bending stresses were taken from 3-7 and 11.

Table 2

TYPICAL STOCKAGES OF DIMENSION LUMBER AND TIMBERS AT LOCAL LUMBERYARDS

Size and Grade	Typical Availability: Generally Available	Typical Availability: Less Frequent
Structural Light Framing		
• 2"x4", 4"x4", S4S, 6' to 16' long, by 2' increments		
- No. 2	x	
- Stud (8' and 10' only)	x	
• Other sizes and grades		x
Light Framing		
• 2"x4", 4"x4", S4S, 6' to 16' long, by 2' increments		
- Construction	x	
- Standard or Better	x	
- Standard		x
- Utility	x	
Joists and Planks		
• 2"x6", 2"x8", 2"x10", 4"x6", 4"x8", S4S, 8' to 20' long in 2' increments		
- No. 1	x	
- No. 2	x	
• Other sizes and grades, and rough lumber		x
Decking		
• 2"x6", tongue and groove, random lengths		
- Select		x
- Commercial	x	
Beams and Stringers		
• All grades, rough		x
• All grades, S4S		x

are of interest, however, since Group 5 is not assigned design stresses. The more common species in these groups are shown in Table 3.

3. Grades - Plywood is graded according to intended use, glue type, wood species and the quality of the veneer making up the outside faces. Veneer grades include "N", which is the highest and is intended for natural finish, and A, B, C and D, which progressively allow greater repaired and unrepaired defects. For expedient blast protection purposes, the sheathing and underlayment grades are both the most suitable and most plentifully available at the local level. Table 4 summarizes these grades and indicates manufactured thicknesses and allowable stress in bending F_b by species group.

D. Typical Plywood Stocks

A typical local lumberyard will stock only a few of the grades and sizes listed in Table 4. Only those thicknesses 1/2" and above will be useful for expedient blast protection purposes. Table 5 lists those grades and sizes often stocked in local lumberyards.

Table 3

CLASSIFICATION OF SPECIES

Group 1	Group 2		Group 3	Group 4	Group 5[a]
Apitong [b][c]	Cedar, Port Orford	Maple, Black	Alder, Red	Aspen	Basswood
Beech, American	Cypress	Mengkulang [b]	Birch, Paper	Bigtooth	Fir, Balsam
Birch	Douglas Fir 2[d]	Meranti, Red [b][e]	Cedar, Alaska	Quaking	Poplar, Balsam
Sweet	Fir	Mersawa [b]	Fir, Subalpine	Cativo	
Yellow	California Red	Pine	Hemlock, Eastern	Cedar	
Douglas Fir 1[d]	Grand	Pond	Maple, Bigleaf	Incense	
Kapur [b]	Noble	Red	Pine	Western Red	
Keruing [b][c]	Pacific Silver	Virginia	Jack	Cottonwood	
Larch, Western	White	Western White	Lodgepole	Eastern	
Maple, Sugar	Hemlock, Western	Spruce	Ponderosa	Black (Western Poplar)	
Pine	Lauan	Red	Spruce	Pine	
Caribbean	Almon	Sitka	Redwood	Eastern White	
Ocote	Bagtikan	Sweetgum	Spruce	Sugar	
Pine, Southern	Mayapis	Tamarack	Black		
Loblolly	Red Lauan	Yellow-poplar	Engelmann		
Longleaf	Tangile		White		
Shortleaf	White Lauan				
Slash					
Tanoak					

(a) Design stresses for Group 5 not assigned.

(b) Each of these names represents a trade group of woods consisting of a number of closely related species.

(c) Species from the genus Dipterocarpus are marketed collectively: Apitong if originating in the Philippines; Keruing if originating in Malaysia or Indonesia.

(d) Douglas fir from trees grown in the states of Washington, Oregon, California, Idaho, Montana, Wyoming, and the Canadian Provinces of Alberta and, British Columbia shall be classed as Douglas fir No. 1. Douglas fir from trees grown in the states of Nevada, Utah, Colorado, Arizona and New Mexico shall be classed as Douglas fir No. 2.

(e) Red Meranti shall be limited to species having a specific gravity of 0.41 or more based on green volume and oven dry weight.

Source: Plywood Design Specification (PDS), American Plywood Association (Revised December 1976).

Table 4

GRADES OF SHEATHING AND UNDERLAYMENT PLYWOOD*

Type and Grade	Available Thickness (in.)
Interior Grades	
(1) C-D Interior**	3/8, 1/2, 5/8, 3/4
(2) Structural I C-D Interior	3/8, 1/2, 5/8, 3/4
(3) Structural II C-D Interior	3/8, 1/2, 5/8, 3/4
(4) Underlayment Interior	1/2, 5/8, 3/4
(5) C-D Plugged Interior	1/2, 5/8, 3/4
(6) Structural I Underlayment	1/2, 5/8, 3/4
(7) Structural II Underlayment	1/2, 5/8, 3/4
(8) 2·4·1 Interior	1-1/8
(9) Appearance Grades (N-N, N-A, N-B, N-D, A-A, A-B, A-D, B-B and B-D	1/4, 3/8, 1/2, 5/8, 3/4
Exterior Grades	
(1) C-C Exterior	3/8, 1/2, 5/8, 3/4
(2) Structural I C-C Exterior	3/8, 1/2, 5/8, 3/4
(3) Structural II C-C Exterior	3/8, 1/2, 5/8, 3/4
(4) Underlayment Exterior	1/2, 5/8, 3/4
(5) Structural I Underlayment	1/2, 5/8, 3/4
(6) Strucutral II Underlayment	1/2, 5/8, 3/4
(7) B-B Plyform Class I Class II	5/8, 3/4
(8) Marine Exterior A-A A-B or B-B	1/4, 3/8, 1/2, 5/8, 3/4
(9) Appearance Grades A-A, A-B, A-C B-B, B-C	1/4, 3/8, 1/2, 5/8, 3/4

* From Plywood Design Specifications (PDS), American Plywood Association, revised December 1976; allowable stresses for usual design are included.

** The first letter designates the grade of the face veneer, the second the back.

Table 5

TYPICAL PLYWOOD STOCKAGES
AT LOCAL LUMBERYARDS

Type and Grade	Thickness	Typical Availability: Generally Available	Typical Availability: Less Frequent
C-D Interior	1/2	x	
	5/8, 3/4		x
Underlayment Interior	1/2, 5/8	x	
	3/4		x
2·4·1 Interior	1-1/8		x
Interior Appearance Grades			
A-D	1/2, 5/8, 3/4	x	
Other Grades	1/2, 5/8, 3/4		x
C-C Exterior	1/2, 5/8	x	
	3/4		x
Underlayment Exterior	1/2, 5/8	x	
	3/4		x
B-B Plyform	5/8, 3/4		x
Exterior Appearance Grades			
A-C	1/2, 5/8, 3/4	x	
Other Grades	1/2, 5/8, 3/4		x

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UPGRADING BASEMENTS FOR COMBINED NUCLEAR WEAPONS EFFECTS: PREDESIGNED EXPEDIENT OPTIONS (UNCLASSIFIED)

By: H. L. Murphy

SRI International (formerly Stanford Research Institute)
Menlo Park, California 94025, October 1977, 200 pages
Contract No. DCPA01-76-C-0315, DCPA Work Unit 1155C

This report is on a continuation of work under a preceding (first-phase) contract concerned with the following: (1) evaluation of a few specific structures, selected in consultation with the Contracting Officer's Technical Representative, DCPA; and (2) devising expedient options for upgrading their structural resistance to blast. The new work was not restricted to expedient options using only indigenous materials and labor, but could also include predesigned options, stored materials, and pre-arrangements for construction trade specialists. The work was to: cover specific "how-to-do-it" applications to be crisis-implemented in a 2- to 3-day period; include quick, inexpensive closure options; and, provide for critical workers remaining behind in "risk areas," plus check of the options' potential for CRP implementation ("host areas"). All applications are to basements, as defined in the first-phase report.*

The second-phase work reported includes:

1. An appendix on predesigns and fabrication of plywood stressed-skin panels (PSSPs). Five kinds of commonly available plywood sheets in four nominal thicknesses, 1/2" to 1-1/8" (13 to 29 mm), were considered in combinations with two strengths of stringers (2x4s to 2x8s) at 4 to 9 stringers per 48-in. (1.22 m) wide PSSP. Included are a complete design procedure, computer program listing (BASIC), data on 628 predesigns, and design tables for 2- to 12-ft spans.

2. An appendix on a design procedure for PSSPs used as intermediate (beam-column) supports for beams/girders in the floor over a potential basement shelter. Future work will use the design procedure, plus how-to-do-it evaluation techniques

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(if such can be developed), to furnish information suitable for use directly by semi-skilled artisans (carpentry).

3. An appendix on using plywood panels by developing a design procedure for their use alone as closures in potential basement shelters. Predesigns have been calculated and development of user tables completed.

4. An appendix reprinted from an earlier report and expanded through preparation of an Addendum that provides simplified charts for use on aperture closures of "2-by" materials (flatwise, plus edgewise for 2x3s to 2x8s† - all in two strength value ranges), again for use by the semi-skilled artisan (carpentry).

5. An appendix covering typical availability of wood and plywood in local lumberyards, plus detailed data on species, sizes, stress grading and some grades.

6. A report main body that is rather brief, confining itself to the quickie design charts and a sort of road-map through the appendices, all aimed at the potential user, a semi-skilled artisan, preferably in carpentry, that might be called on to quickly construct the predesigned items for use in converting an existing basement into potential shelter.

Further work is needed in this research area, most especially in this wood use area and on tests to determine resistance behavior through the full range of loadings to collapse - of PSSPs, plywood panels and wood beams. Close collaboration between analytical research and tests projects is needed.

The Introduction section and Appendix C were prepared by a colleague, E. E. Pickering, Sr. Civil Engineer, whose efforts are gratefully acknowledged.

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* Murphy, H.L., C.K.Wiehle and E.E.Pickering, Upgrading Basements for Combined Nuclear Weapons Effects: Expedient Options, SRI International (formerly Stanford Research Institute) Technical Report, for U.S. Defense Civil Preparedness Agency, May 1976. (AD-A030 762)

† Nominal cross-section dimensions (38x64 to 38x184 mm, actual dimensions).

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5622 & 6876

May 4, 1978

Murphy, H. L., Upgrading Basements for Combined Nuclear Weapons Effects: Predesigned Expedient Options, SRI International Technical Report for U.S. Defense Civil Preparedness Agency, October 1977.

Reference: Contracts DCPA01-76-C-0315 and -77-C-0227; Work Unit 1155C

To: Distribution List for above report

1. The report includes, on page 27, an acknowledgment of the considerable assistance readily given by the staff and Head, Engineering Service, Applied Research Department, American Plywood Association, Tacoma, Washington 98401. Such assistance included supplying a copy, to accompany each copy of this report distribution, of their publication Plywood Design Specification, Revised December 1976, which is Reference 5 of the main body of this report, as well as Reference 2 of Appendices A1 and A2 and Reference 1 of Appendix A3; this generous action is also gratefully acknowledged.

2. Included with this distribution as loose extra sheets are an updated and a new table (Tables 8.0A and 8.0A (Addendum), respectively) for the "Slanting" guidance developed over the years by the undersigned and various co-authors. Distribution is made herewith because those receiving this report have, in general, also received the slanting reports (of which a complete list is on the reverse side of the Table 8.0A sheet).

3. Also enclosed is an ERRATA sheet concerning a one-way R/C slab design chart published in the same "Slanting" guidance and, unfortunately, picked-up in a DCPA TR- publication.

H. L. Murphy
SRI Project Leader
(H. L. Murphy Associates)

cc: Contracting Officer, DCPA
Dr. M. A. Pachuta, DCPA (COTR)
R. A. Adams, SRI Contracts

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Table 8.0A

SUMMARY OF SLANTING COST ESTIMATES (15 psi)

Building:		(1) 2A (closed)		(2) 2B (open portion)		(3) 2B (closed portion)		(4) 2B (total)		(5) 2C ("open")		(6) 3A (closed) with mezzanine		(7) 3A (closed) no mezzanine		(8) 4A (open)	
Cost Items		All	Non-deferrable	All	Non-deferrable	All	Non-deferrable	All	Non-deferrable	All	Non-deferrable	All	Non-deferrable	All	Non-deferrable	All	Non-deferrable
Shelter area (sf)		3,378		2,262		1,116		3,378		3,465		16,351		13,598		130,522	
Estimate date		6-70		6-70		6-70		6-70		6-70		6-70		6-70		6-70	
A. Structural	$	14,354	14,354	13,399	13,399	8,154	8,154	21,553	21,553	20,913	20,913	67,667	57,220	56,021	55,220	498,824	498,824
	$/sf	4.25	4.25	5.92	5.92	7.31	7.31	6.38	6.38	6.03	6.03	4.14	3.50	4.12	4.06	3.82	3.82
	%*	57	99	90	91	85	96	88	93	62	>99	67	96	63	96	63	64
	%†		*100*		*100*		*100*		*100*		*100*		*85*		*99*		*100*
B. Blast doors	$	2,478	--	99	--	1,139	--	1,238	--	3,943	--	17,265	--	17,265	--	22,738	9,730
	$/sf	.73	--	.04	--	1.02	--	.37	--	1.14	--	1.06	--	1.27	--	.17	.07
	%*	10	--	1	--	12	--	5	--	12	--	17	--	19	--	3	1
	%†		*0*		*0*		*0*		*0*		*0*		*0*		*0*		*43*
C. Ventilation	$	6,270	99	376	376	343	343	719	719	6,270	99	11,814	-760	11,814	-760	233,585	233,585
(Incl. emergency	$/sf	1.86	.03	.17	.17	.31	.31	.21	.21	1.81	.03	.72	-.05	.87	-.06	1.79	1.79
exit tunnel,	%*	25	1	3	3	3	4	3	3	19	--	12	-1	13	-1	30	30
if any)	%†		*2*		*100*		*100*		*100*		*<1*		*-6*		*-6*		*100*
D. Other	$	2,270	--	1,027	1,027	--	--	1,027	1,027	2,635	--	3,757	3,043	3,757	3,043	35,697	35,697
	$/sf	.67	--	.45	.45	--	--	.30	.30	.76	--	.23	.19	.28	.22	.27	.27
	%*	9	--	7	7	--	--	4	4	8	--	4	5	4	5	5	5
	%†		*0*		*100*		*0*		*100*		*0*		*81*		*81*		*100*
Total	$	25,372	14,453	14,901	14,802	9,636	8,497	24,537	23,299	33,761	21,012	100,503	59,503	88,857	57,503	790,844	777,836
	$/sf	7.51	4.28	6.59	6.54	8.63	7.61	7.26	6.90	9.74	6.06	6.15	3.64	6.53	4.23	6.06	5.96
	%†		*57*		*99*		*90*		*95*		*62*		*59*		*65*		*98*
‡ Jan. 68:	$/sf	6.04	3.44	5.30	5.26	6.94	6.12	5.84	5.55	7.84	4.88	4.95	2.93	5.25	3.40	4.88	4.80
‡ Sep. 77:	$/sf	13.79	7.86	12.10	12.01	15.84	13.97	13.33	12.67	17.88	11.13	11.29	6.68	11.99	7.77	11.13	10.94

* Percent ratio of item cost to total cost.
† Percent ratio of nondeferrable cost to item (All) cost.
‡ Using Engineering News-Record Building Cost Index to convert totals from San Francisco area to EN-R's 20-cities average and from estimate date to date(s) shown.

11/15/77
H.L.Murphy

Updated version of:

Table 8.0A SUMMARY OF SLANTING COST ESTIMATES (15 psi)

in publication:

Murphy, H. L., J. R. Rempel, and J. E. Beck, SLANTING IN NEW BASEMENTS FOR COMBINED NUCLEAR WEAPONS EFFECTS: A Consolidated Printing of Four Technical Reports, Stanford Research Institute Technical Reports, 3 vols., for U. S. Defense Civil Preparedness Agency, October 1975. (AD-A023 237)

The four reports that together make up the above publication are:

Murphy, H. L., Feasibility Study of Slanting for Combined Nuclear Weapons Effects (Revised), Stanford Research Institute Technical Report, for U.S. Office of Civil Defense, 2 vols., July 1971. (AD-734 831 and 2)

Murphy, H. L., and J. R. Rempel, Slanting for Combined Nuclear Weapons Effects: FIRE HAZARD REDUCTION, Stanford Research Institute Technical Report, for U.S. Defense Civil Preparedness Agency, August 1972. (AD-763 472)

Murphy, H. L., and J. E. Beck, Slanting for Combined Nuclear Weapons Effects: EXAMPLES WITH ESTIMATES, AND AIR BLAST ROOM FILLING, Stanford Research Institute Technical Report, for U.S. Defense Civil Preparedness Agency, June 1973. (AD-783 061)

Murphy, H. L., and J. E. Beck, Slanting for Combined Nuclear Weapons Effects: BLAST-RESISTANT DESIGN/ANALYSIS WITH EXAMPLES, Stanford Research Institute Final Report, for Defense Civil Preparedness Agency, December 1974. (AD-A016 631)

In addition, a report has been published that provides further material for incorporation in the above slanting guidance:

Murphy, H. L., and J. E. Beck, Maximizing Protection in New EOCs from Nuclear Blast and Related Effects: Guidance Provided by Lecture and Consultation, Stanford Research Institute Technical Report, for U.S. Defense Civil Preparedness Agency, September 1976. (AD-A039 499)

Table 8.0A (Addendum)

ENGINEERING NEWS-RECORD COST INDEXES USED*

BASE: 1913 = 100

Month and Year	EN-R Issue Date	EN-R Issue Page	20-Cities Average† Building Cost Index	20-Cities Average† Constrn Cost Index	San Francisco Building Cost Index	San Francisco Constrn Cost Index
12/67	12/21/67	88	690	1103	764	1318
1/68	3/21/68	85	692	1107	765‡	1317‡
3/68	3/21/68	77	698	1117	768	1316
6/68	6/20/68	118	718	1154	781	1329
6/70	9/17/70	87	830	1369	857	1515
6/71	6/17/71	82	944	1575	1003	1709
6/73	6/21/73	101	1138	1896	NA	NA
3/76	3/18/76	63/67	1378	2322	1514	2813
			BASE: 1967 = 100			
1/68			103	103	114	123
6/68			107	108	116	124
6/70			124	128	128	142
9/77	9/22/77	67	235	246	NA	NA

* In Tables 8.0A through E, to convert from estimates based on 6/68 and 6/70 San Francisco costs to 1/68, 6/71 (report) and 6/73 (report) "20-cities average" estimates.[81]

† All Indexes above are 1913 = 100 base. To convert "20-cities average" Indexes to 1967 = 100 base, divide 1913 = 100 base values by following factors: BCI, 6.7154; CCI, 10.704; MCC, 2.9433.

‡ Obtained by interpolation between 12/67 and 3/68 values.

11/15/77
H.L.Murphy

Updated version of:

Table 8.0A (Addendum) ENGINEERING NEWS-RECORD COST INDEXES USED

in publication:

Murphy, H. L., and J. E. Beck, Maximizing Protection in New EOCs from Nuclear Blast and Related Effects: Guidance Provided by Lecture and Consultation, Stanford Research Institute Technical Report, for U.S. Defense Civil Preparedness Agency, September 1976. (AD-A039 499)

5/1/78
H.L.Murphy

ERRATA

An error has been found and reported to me - by someone unidentified but to whom I am grateful - in one of the design charts for simply supported one-way R/C slabs, as published in the combined nuclear effects slanting guidance over past years. It has, unfortunately, been also published in a DCPA TR- publication, as indicated below.

In the figures indicated below: Change p' appearing on the topmost four (nearly horizontal) curves, to p_v

Figure 6-6E (page 6-48) published in:

Murphy, H. L., J. R. Rempel, and J. E. Beck, SLANTING IN NEW BASEMENTS FOR COMBINED NUCLEAR WEAPONS EFFECTS: A Consolidated Printing of Four Technical Reports, SRI International (formerly Stanford Research Institute) Technical Reports, 3 vols., for U.S. Defense Civil Preparedness Agency, October 1975. (AD-A023 237)

and in

Murphy, H. L., and J. E. Beck, Slanting for Combined Nuclear Weapons Effects: BLAST-RESISTANT DESIGN/ANALYSIS WITH EXAMPLES, SRI International (formerly Stanford Research Institute) Technical Report, for U.S. Defense Civil Preparedness Agency, December 1974. (AD-A016 631)

Figure A-4(a) (page A-10) published in:

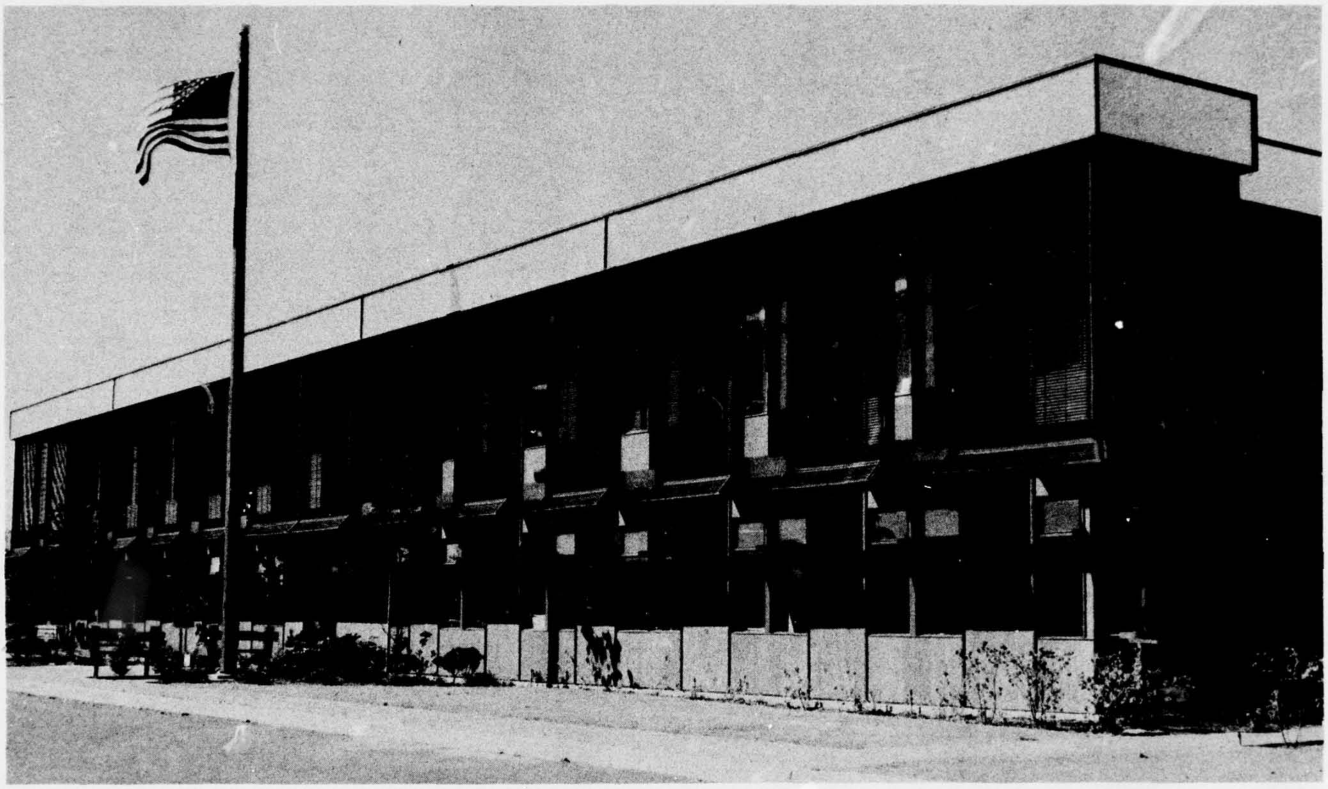
PROTECTIVE CONSTRUCTION, TR-20-(VOL. 4), U.S. Defense Civil Preparedness Agency, Washington, D.C. 20301, May 1977.

Plywood Design Specification

Published by the American Plywood Association

PDS

Revised December 1976



The American Plywood Association Research Center in Tacoma, Washington is a million dollar commitment by the plywood industry dedicated to the assurance of a quality product and the development of more efficient and economical building systems.

The Research Center is staffed with approximately 50 professional engineers, wood scientists, foresters and support personnel. Their assignment directly or indirectly benefits all specifiers and users of plywood.

Bronson J. Lewis

Executive Vice President

FOREWORD

This Specification presents section properties, recommended design stresses, and design methods for plywood. The information stems from extensive and continuing test programs conducted by the American Plywood Association, by other wood associations, and by the United States Forest Products Laboratory, and is supported by years of satisfactory experience. Information in this Specification applies to construction and industrial plywood made in accordance with U.S. Product Standard PS 1, promulgated by the United States Department of Commerce.

The technical data in this Specification are presented as the basis for competent engineering design. For such design to result in satisfactory service, adequate materials and fabrication are also required.

All plywood should bear the APA grade-trademark of the American Plywood Association. All lumber should bear the grademark of a recognized lumber-grading agency.

As they are developed, Supplements will be added to this Specification, presenting design methods for glued plywood components and other units where plywood performs a major structural function, as in diaphragms and folded plates.

The plywood use recommendations contained in this publication are based on American Plywood Association's continuing program of laboratory testing, product research and comprehensive field experience. However, there are wide variations in quality of workmanship and in the conditions under which plywood is used. Because the Association has no control over those elements of fabrication, it cannot accept responsibility for plywood performance or for designs as actually constructed.

Technical Services Division
American Plywood Association

KEY TO TABLES

KEY TO FIGURES

PLYWOOD DESIGN SPECIFICATION

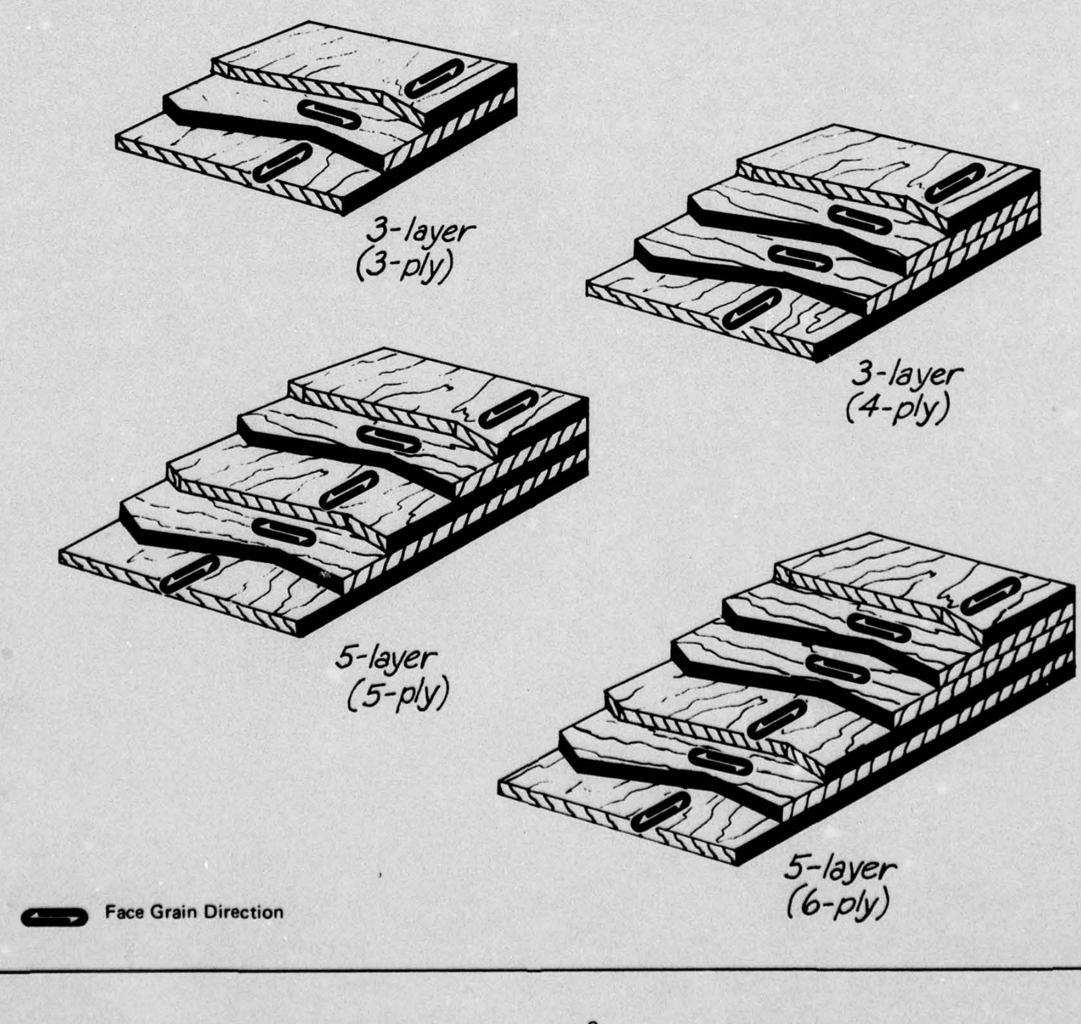
TABLE OF CONTENTS

1. GENERAL REQUIREMENTS FOR PLYWOOD STRUCTURAL DESIGN

This publication presents section properties, allowable stresses, and practices to be followed in design with plywood. Presentation of this design information is not intended to preclude further development. Where adequate test data are available, therefore, the design properties and provisions may be appropriately modified. If they are modified, any such change must be noted when referring to this publication.

In this specification the word "shall" is mandatory and the word "should" is advisory. Explanatory information and examples are included throughout this Specification in *italics* to aid the user, and are not a formal part of the Specification.

Figure 1.1 Typical three- and five-layer construction with parallel-laminated cross bands in the 4- and 6-ply panels.



1.1 SCOPE

1.1.1 Practice Defined

This Specification defines the practice to be followed in structural design with plywood when used in conventional, mechanically fastened applications, and in the design of glued structural assemblies using plywood.

1.1.2 Competent Supervision

The plywood section properties given in Tables 1 and 2, and the allowable unit stresses given in Table 3, are for designs made and carried out under competent supervision, and for plywood of assured type and grade.

1.2 PLYWOOD MANUFACTURE

The manufacturing steps for construction and industrial plywood are basically the same for all species. Plywood is manufactured with an odd number of layers, each layer consisting of one or more sheets of veneer (thin sheets of wood). The layers are glued together with the grain of adjacent layers at right angles. (See Figure 1.1.) Veneer for panels covered in this Specification is usually "rotary peeled" rather than sliced or sawn.

Plywood is manufactured from peeler logs cut into "blocks" usually about 8 1/2 feet long. The blocks are then placed in a giant lathe and rotated against a long knife which peels the wood off in long, continuous, thin sheets known as veneer. The veneer is conveyed to clippers which cut it to desired widths, after which it is run through dryers and reduced to about two to five percent moisture content. After careful grading, the veneer goes to the glue spreaders where adhesive is applied and the plywood panel is laid up.

The plywood is then generally hot-pressed in a large multi-opening hydraulic press. The application of both heat and pressure cures the glue in a matter of minutes. After removal from the press, panels are trimmed to size, and some grades are sanded. Plywood produced by American Plywood Association member mills to conform with U.S. Product Standard PS 1 carries a grade-trademark on every panel. This mark permits easy identification and assures the consumer of a quality product.

1.2.1 Product Standard

Plywood type, grade, and species group where required, shall be specified by commercial designations as outlined in the latest edition of UNITED STATES PRODUCT STANDARD PS 1 FOR CONSTRUCTION AND INDUSTRIAL PLYWOOD.

1.3 PLYWOOD TYPE

Plywood is made in two types, Interior and Exterior. This classification is made on the basis of resistance of the panels to moisture.

Some allowable stresses vary with the type of panel, whether Interior or Exterior. Shear strength, however, varies with the kind of glue used.

Exterior-type plywood is distinguished from Interior-type plywood by its superior resistance to moisture and weather. The difference is due to more than the glue. Exterior plywood is not only made with fully water-proof glue, but also has a restriction that no veneer grade below C is allowed. As a result of this restriction, some panels are marketed as "Interior plywood with exterior glue," or "Interior panels with intermediate glue."

1.3.1 Interior

Interior-type plywood may be used if its equilibrium moisture content (1) in service does not continuously or repeatedly exceed 18%, and if it is not exposed to the weather.

Interior-type plywood includes some grades which are manufactured with exterior glue but whose veneers do not have to meet all the requirements for Exterior-type plywood. Such plywood is excellent for sheathing where long construction periods are expected; and for some protected exposures where a high moisture level might some time be reached. Because of the veneer grades used, it does not fully qualify as Exterior type plywood, and some panels may develop localized glueline delaminations when permanently exposed to the weather. An additional advantage is realized in that "Interior with exterior glue" permits the use of the same shear stresses as those for Exterior plywood.

1.3.2 Exterior

Plywood that is exposed to the weather, or whose equilibrium moisture content for other reasons continuously or repeatedly exceeds 18% shall be of Exterior type.

(1) See Appendix for definition of any terms which may be unfamiliar, such as "equilibrium moisture content".

1.4 PLYWOOD GRADE

Plywood produced under PS 1 is graded according to one of two basic systems. The first system includes the "Engineered Grades", consisting largely of the unsanded sheathing panels designated C-D Interior or C-C Exterior. Either of these grades may be modified by the terms STRUCTURAL I or II [2]. Plywood panels conforming to this system are designated by a thickness and an Identification Index, without reference to veneer species. See Section 1.4.1.

Plywood panels of several grades may be modified by the STRUCTURAL designation. This term is intended to identify panels conforming to special provisions of PS 1. Structural grades are intended for use where strength properties are of maximum importance, as in plywood components. STRUCTURAL I is limited to Group 1 species. (See Section 1.5 for Species Groups). STRUCTURAL II allows Species Groups 1, 2 and 3. Both are made only with exterior glue, and have some further restrictions, as on knot size and repairs.

Panels in grades other than those mentioned above are the "Appearance" grades, designated by the panel thickness, by the veneer classification of face and back veneers, and by the species group of the veneers. PLYFORM is an exception, where Class designates a species mix.

1.4.1 Identification Index

The Identification Index used on sheathing panels is a measure of plywood stiffness and strength parallel to the face grain. It consists of two numbers presented in a manner similar to a fraction. The number on the left of the Identification Index gives the maximum spacing for roof supports under average loading conditions (good for 35 psf live load, or better). The number on the right of the slash shows the maximum spacing for floor supports, again under average residential loading. (Maximum allowable uniform loads vary, but all are over 160 psf. Strength is adequate to carry heavy concentrated loads such as pianos, home freezers, water heaters, etc.).

The Identification Index system for sheathing-grade panels was established to simplify specification of plywood for roof sheathing or subflooring without resorting to specific structural-engineering design. This system indicates sheathing performance without the need to refer to species group or panel thickness. It gives the allowable span for roof sheathing and the allowable span for subflooring for normal residential uses when the face grain is placed across supports.

For roof sheathing, therefore, on a 24-inch span, the user will specify a 24/0 C-D INT-APA panel, which in actuality might be 3/8" Group 1, or 1/2" Group 2, 3, or 4 plywood. So that there need be no problem with differing thicknesses on the same job, panels should also be specified as to thickness. Initially, the user might not care whether his 24/0 plywood were 3/8" or 1/2", but if he reordered he would wish to have the same thickness with which he started. His reorder, then, might read 3/8", 24/0 C-D INT-APA.

Note that each Identification Index number applies to several different panel constructions, with similar strength and stiffness. Thus, the section properties listed may be quite conservative for some panels.

1.4.2 Veneer Classifications

Veneer is divided into essentially five levels as follows: *(These veneer classifications are referred to as "veneer grades.")*

N and A	– Highest grade level. No knots, restricted patches. *N is intended for natural finish while A is intended for a paintable surface.*
B	– Solid surface – Small round knots. Patches and round plugs are allowed. *Most common use is faces for PLYFORM.*
C Plugged	– Special improved C grade. *Used in UNDERLAYMENT.*
C	– Small knots, knotholes, patches. Lowest grade allowed in Exterior-type plywood. *For sheathing faces and inner plies in Exterior panels.*
D	– Larger knots, knotholes, some limited white pocket in sheathing grades. This grade permitted only in Interior-type panels. *For inner plies and backs in Interior panels.*

(2) Check local suppliers for availability of STRUCTURAL II.

1.5 WOOD SPECIES

The woods which may be used to manufacture plywood under U.S. Product Standard PS 1 are classified into five groups based on elastic modulus in bending, and important strength properties. Most woods listed in Table 1.5 are individual species but some are trade groups of related species commonly traded under a single name without further identification.

Design stresses for a group are determined from the clear wood group assignments developed using principles set forth in ASTM D 2555, ESTABLISHING CLEARWOOD STRENGTH VALUES. Design stresses are published for groups one through four. All woods within a group are assigned the same working stress.

The species grouping system is designed to simplify the design and identification that would otherwise be necessary for the seventy-some species and trade groups of wood from which plywood may be manufactured. Thus, the designer need only concern himself with four design stress groups rather than seventy.

The group classification of a plywood panel is usually determined by the face and back veneer with the inner veneers allowed to be of a different group. Certain grades such as MARINE and the STRUCTURAL I grades, however, are required to have all plies of Group I species.

Table 1.5 Classification of Species

Group 1	Group 2		Group 3	Group 4	Group 5 [a]
Apitong [b][c]	Cedar, Port Orford	Maple, Black	Alder, Red	Aspen	Basswood
Beech, American	Cypress	Mengkulang [b]	Birch, Paper	Bigtooth	Fir, Balsam
Birch	Douglas Fir 2[d]	Meranti, Red [b][e]	Cedar, Alaska	Quaking	Poplar, Balsam
Sweet	Fir	Mersawa [b]	Fir, Subalpine	Cativo	
Yellow	California Red	Pine	Hemlock, Eastern	Cedar	
Douglas Fir 1[d]	Grand	Pond	Maple, Bigleaf	Incense	
Kapur [b]	Noble	Red	Pine	Western Red	
Keruing [b][c]	Pacific Silver	Virginia	Jack	Cottonwood	
Larch, Western	White	Western White	Lodgepole	Eastern	
Maple, Sugar	Hemlock, Western	Spruce	Ponderosa	Black (Western Poplar)	
Pine	Lauan	Red	Spruce		
Caribbean	Almon	Sitka	Redwood	Pine	
Ocote	Bagtikan	Sweetgum	Spruce	Eastern White	
Pine, Southern	Mayapis	Tamarack	Black	Sugar	
Loblolly	Red Lauan	Yellow-poplar	Engelmann		
Longleaf	Tangile		White		
Shortleaf	White Lauan				
Slash					
Tanoak					

(a) Design stresses for Group 5 not assigned.

(b) Each of these names represents a trade group of woods consisting of a number of closely related species.

(c) Species from the genus Dipterocarpus are marketed collectively: Apitong if originating in the Philippines; Keruing if originating in Malaysia or Indonesia.

(d) Douglas fir from trees grown in the states of Washington, Oregon, California, Idaho, Montana, Wyoming, and the Canadian Provinces of Alberta and British Columbia shall be classed as Douglas fir No. 1. Douglas fir from trees grown in the states of Nevada, Utah, Colorado, Arizona and New Mexico shall be classed as Douglas fir No. 2.

(e) Red Meranti shall be limited to species having a specific gravity of 0.41 or more based on green volume and oven dry weight.

2. PLYWOOD SECTION PROPERTIES

2.1 APPLICATION

Engineering section properties per foot of width are presented in Tables 1 and 2, page 16. The tables are to be used for species and grade combinations as indicated in the "Guide to Use of Stress and Section Properties Tables," page 14. The section properties shall be used in conjunction with the allowable stresses for the species group of the face plies. Stresses are as given in Table 3, page 17.

Section properties from Table 1 shall apply for all panels having veneers from mixed species groups, including most grades covered by Product Standard PS 1. Table 2 applies to panels having all veneers from the same species group. Grades included in Table 2 are STRUCTURAL I and MARINE. Both Tables 1 and 2 have separate section properties for unsanded, sanded and touch-sanded panels. Grades normally touch-sanded are UNDERLAYMENT, C-D plugged and C-C plugged.

Section properties for plywood are presented so that the engineer may design with the material as if it were a homogeneous orthotropic plate – a plate with different properties in the three directions. By using the corrected, or "effective" properties, the engineer need not concern himself with the actual multilayered makeup of the material.

The "effective" section properties presented in Tables 1 and 2 are computed by the transformed-section technique, taking into account the orthotropic nature of wood, the species groups used for outer and inner plies, and the manufacturing variables involved for each grade. Because these tables, in order to remain concise, represent a wide variety of grades and constructions possible under the Product Standard, the section properties presented are generally the minimums that can be expected. Hence, the actual panel obtained in the market place will usually have a section property greater than that represented in this Specification.

Note that the section properties are reported per foot of width, and referred to the face grain direction. Where the stress is applied parallel to the face grain, the "parallel" section property should be used. Such is the case for most applications, where the panel is installed with the grain of the face plies across the supports. When stresses will be introduced in the cross-panel direction, the "perpendicular" properties should be used. This condition occurs when the panel is installed with the face grain parallel to the supports. For further detail note Figure 2.1 for a standard four-by-eight-foot panel.

The section properties included in Tables 1 and 2 are independent of the number of plies used in panel construction. For the majority of plywood applications, the specification of plywood type and grade is sufficient. However, in certain critical designs, such as slave pallets and panelized roofs, the panel construction may be critical. If such information is required for a particular design, it may be obtained from the Technical Services Division, American Plywood Association.

Normally all panels with A or B grade faces are sanded. Sheathing grade panels such as C-D and C-C are unsanded. UNDERLAYMENT and the plugged grades are "touch-sanded," and consequently have different section properties. Sanded section properties should be used for overlaid panels such as MDO or HDO.

2.2 DIRECTION OF FACE GRAIN

Section properties parallel to the face grain of the plywood are based on a panel construction which gives minimum values in that direction. Properties perpendicular to the face grain are based on a (usually) different panel construction, which gives minimum values in that direction. Both values, therefore, are conservative. Properties for the two directions, however, can not be added to achieve properties of the full panel.

The reason for using different layups in calculation is that plywood mills may use different layups for the same panel thickness to make optimum use of raw materials. For a standard four-by-eight-foot plywood panel, the face-grain direction is parallel to the eight-foot edge (Figure 2.1). Design calculations must take into account in which direction the stresses will be imposed in the panel. If stresses can be expected in both directions, then both the parallel and perpendicular directions should be checked.

2.3 WEIGHT

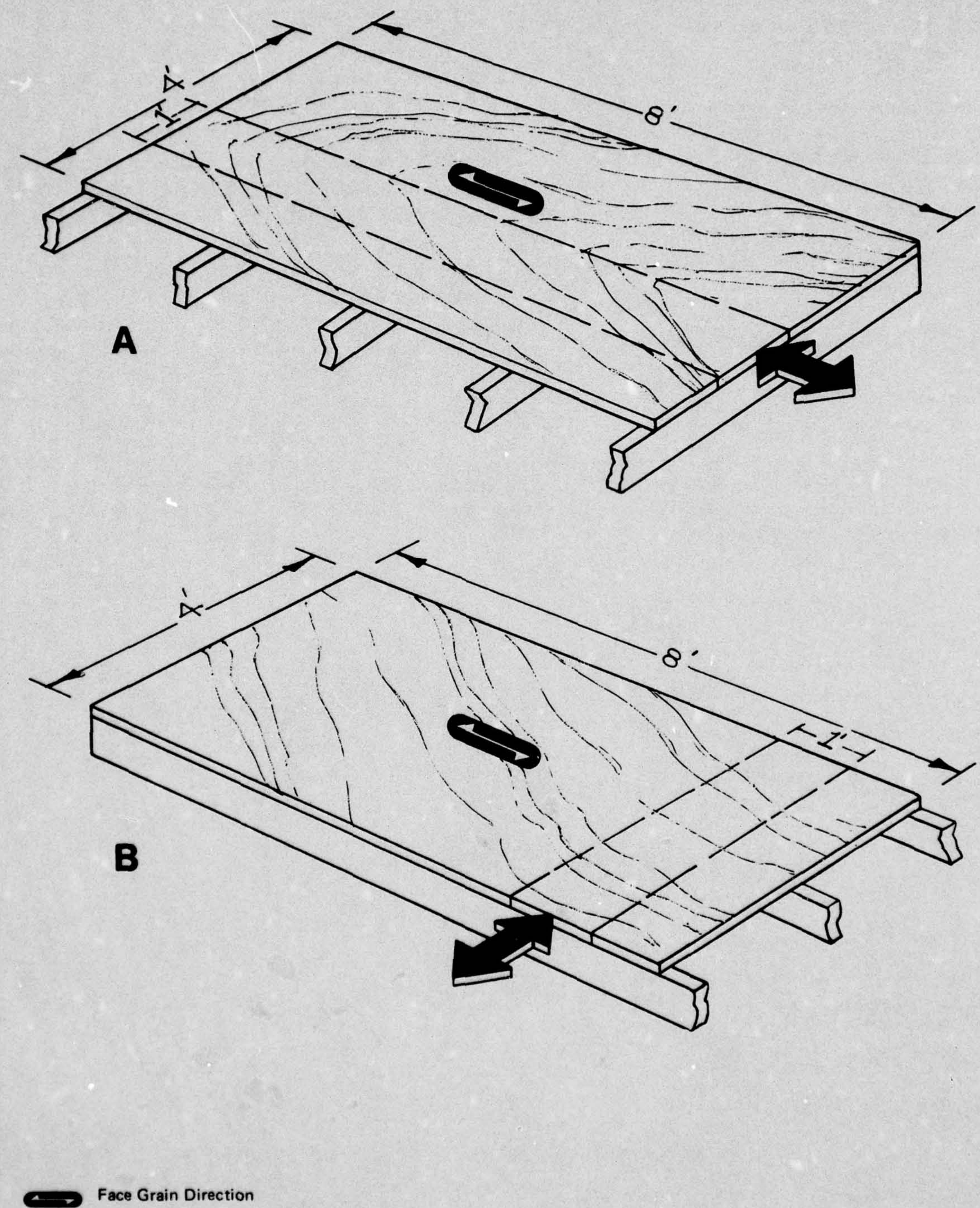
Approximate plywood weight in pounds per square foot (psf) for calculating actual dead loads shall be as given in Column 2 of Tables 1 and 2.

2.4 THICKNESS (EXCEPT SHEAR)

Plywood thickness for calculation shall be the nominal thickness as given in Column 1 of Tables 1 and 2, except in calculating shear-through-the-thickness.

Plywood panel thickness used for computing section properties was the nominal thickness minus one-half of the allowable thickness tolerance permitted under Product Standard PS 1. This less-than-nominal thickness

Figure 2.1 Typical plywood panel with face grain direction perpendicular to, or across supports (A) and parallel to supports (B). Note standard 4' x 8' size, face grain direction, and representative portion of panel used in calculation of section properties for stress parallel (A) or perpendicular (B) to the face grain.



insures that engineering computations will represent the near minimum that could be encountered in the market place.

2.5 THICKNESS FOR SHEAR

Plywood panel thickness for calculation of shear-through-the-thickness shall be as given in Column 3 of Tables 1 and 2. It shall be used in conjunction with the allowable shear stresses given in Table 3 for the species group of the face plies.

The calculated effective thickness for shear-through-the-thickness includes provisions to compensate for the reduced effectiveness of inner plies in mixed-species panels and also for the additional shear resistance afforded by the glue. The resulting value is directly related to veneer thickness, panel construction and number of glue lines in the panel. An explanation of shear-through-the-thickness is provided in Section 3.8.1.

2.6 AREAS FOR TENSION AND COMPRESSION

Effective areas for calculation of allowable tension and compression shall be as given in Columns 4 and 8 of Tables 1 and 2. The allowable tension or compression stress to be used with these areas is that given in Table 3 for the species group of the face veneers.

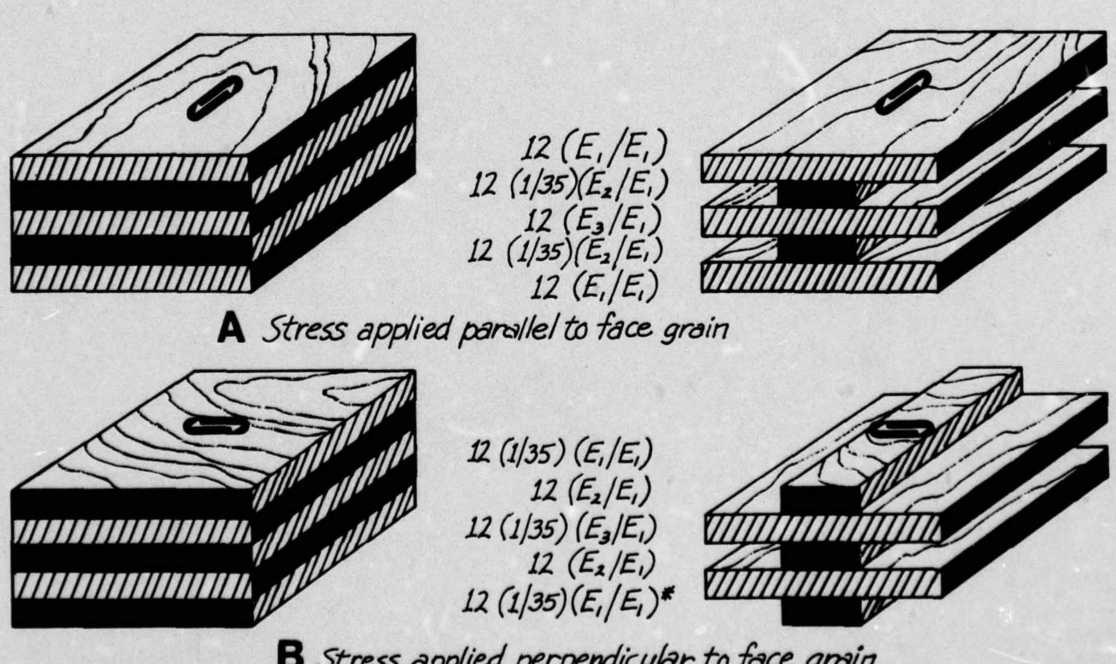
Areas effective for tension and compression are based on those plies whose grain is parallel with the stress, since perpendicular plies are assumed to contribute essentially nothing to tensile and compressive strength.

2.7 MOMENT OF INERTIA

Effective moments of inertia shall be as given in Columns 5 and 9 of Tables 1 and 2. They shall be used in stiffness calculations, in conjunction with the modulus of elasticity given in Table 3 for the species group of the face plies. THEY SHALL NOT BE USED IN BENDING-STRESS CALCULATIONS.

The effective moments of inertia listed in Tables 1 and 2 have been adjusted to account for several variables, with the result that the adjusted values presented in the table may be used in conjunction with the modulus of elasticity of the face plies, in either direction, without reference to actual physical make-up of the panel. These effective properties were calculated with adequate recog-

Figure 2.2 Transformed sections for a five-layer (5-ply) plywood panel. Gross cross sections on the left and transformed cross sections on the right. Transformed sections used for calculating listed section properties for stress parallel (A) and perpendicular (B) to the face grain.



*Note: This ply ignored in calculation of section modulus, KS. See Section 2.8

Face Grain Direction

nition for the reduced effectiveness of perpendicular plies. The need for making these adjustments stems from the fact that the actual modulus of elasticity of peeled wood veneer perpendicular to the grain is only about 1/35 that of its parallel modulus. Also compensated is the effect of use of the weakest permitted species group. Figure 2.2 shows a plywood cross section for a five-ply, five-layer panel and its transformed section for computation.

Moment of inertia, I, may be used only in stiffness calculations, with KS used in bending-stress calculations. The reason for this practice is that, for some applications of plywood, section modulus is not simply equal to moment of inertia I, divided by distance to extreme fiber, c. See next section on section modulus. Note that the "I" listed is for panels used "flat" with loads applied perpendicular to the plane of the panel. For computing I of panels loaded on edge, in plane of plies, see Plywood Design Specification Supplement 2, DESIGN OF PLYWOOD BEAMS.

2.8 SECTION MODULUS

Effective section moduli for plywood shall be as given in Columns 6 and 10 of Tables 1 and 2. They shall be used in bending-stress calculations in conjunction with the allowable stresses in flexure for the species group of the face plies, from Table 3.

The effective section moduli presented have been computed taking into account species of plies, direction, and an empirical correction factor "K". The computations follow the principles presented in U. S. Forest Service Research Note FPL-059, BENDING STRENGTH AND STIFFNESS OF PLYWOOD.

The tabulated KS values must always be used in calculations for bending strength, rather than using I/c. The reason is that, in accordance with FPL-059, section moduli perpendicular to the grain have been calculated ignoring the outermost tension ply. This outermost ply on the tension side of a plywood panel stressed perpendicular to face grain adds little strength to the panel.

Note that the KS listed is for panels used "flat". For computing S of panels used vertically see Plywood Design Specification Supplement 2, DESIGN OF PLYWOOD BEAMS.

2.9 ROLLING-SHEAR CONSTANT

The rolling-shear constant, Ib/Q, from Column 7 or 11 of Tables 1 and 2 shall be used in conjunction with the allowable stress in rolling shear listed in Table 3 for the appropriate type and grade of plywood.

The rolling-shear constant is presented simply as a convenience for use in the usual shear equation $V = F_s(Ib/Q)$.

For certain plywood constructions the rolling-shear constant has been omitted from the table because with that construction, rolling shear could not control the design. A graphic description of rolling shear is shown in Figure 3.3, page 21.

3. STIFFNESS AND DESIGN STRESSES FOR PLYWOOD

3.1 GENERAL

The allowable unit stresses and moduli of elasticity presented in Table 3, or modifications thereof, shall be used in accordance with the provisions of this Specification. Actual stress, computed on the basis of section properties given in Section 2, shall not exceed the allowable unit stresses shown in Table 3, except as hereafter modified for loading condition, treatment, or moisture content. Moduli of elasticity and allowable stresses for species group of the faces are to be used, in both parallel and perpendicular directions. Plywood with finger or scarf joints manufactured in accordance with U.S. Product Standard PS 1 may be assumed to carry full allowable stresses as reported in Table 3.

The designer may use the allowable stresses assigned to the species group used for the face plies, regardless of actual species used in inner plies, since section properties have been adjusted to compensate for such differing materials.

To assist the designer in application of Tables 1 through 3, a guide to the use of these tables has been provided. The purpose of this guide is to present those plywood grades that are most often used in engineering design, and relate them to the tables of section properties and allowable stresses.

The allowable stresses reported in Table 3 are the result of continuing research by the Technical Services Division of the American Plywood Association.

3.1.1 Plywood Grade Identification

When the allowable stresses in Table 3 are used, the plywood shall be manufactured in accordance with U.S. Product Standard PS 1, and shall be identified by the APA grade-trademark of the American Plywood Association.

(Section 3 continued on page 18)

Guide to Use of Allowable Stress and Section Properties Tables

PLYWOOD TYPE	PLYWOOD GRADE	DESCRIPTION AND USE	TYPICAL GRADE–TRADEMARKS	VENEER GRADE FACE	VENEER GRADE BACK	VENEER GRADE INNER	COMMON THICKNESSES	GRADE STRESS LEVEL (TABLE 3)	SPECIES GROUP	SECTION PROPERTY TABLE
INTERIOR TYPE PLYWOOD	C-D INT-APA	Unsanded sheathing grade for wall, roof, subflooring, and industrial applications such as pallets and for engineering design, with proper stresses. Also available with intermediate and exterior glue (1). For permanent exposure to weather or moisture only Exterior type plywood is suitable.	C-D 32/16 APA INTERIOR PS 1-74 000	C	D	D	5/16, 3/8, 1/2, 5/8, 3/4	S-3 (1)	See "Key to Identification Index"	Table 1 (unsanded)
	STRUCTURAL I C-D INT-APA or STRUCTURAL II C-D INT-APA (2)	Plywood grades to use where strength properties are of maximum importance, such as plywood-lumber components. Made with exterior glue only. Structural I is made from all Group 1 woods. Structural II allows Group 3 woods.	STRUCTURAL I C-D 42/20 APA INTERIOR PS 1-74 000 EXTERIOR GLUE	C	D	D	5/16, 3/8, 1/2, 5/8, 3/4	S-2	Structural I Use Group 1 Structural II Use Group 3	Table 2 (unsanded)
	UNDERLAYMENT INT-APA	For underlayment or combination subfloor-underlayment under resilient floor coverings. Available with exterior glue. Touch-sanded. Available with tongue and groove.	UNDERLAYMENT GROUP 3 APA INTERIOR PS 1-74 000 EXTERIOR GLUE	C plugged	D	C & D	1/2, 19/32, 5/8, 23/32, 3/4	S-3 (1)	As Specified	Table 1 (touch-sanded)
	C-D PLUGGED INT-APA	For built-ins, wall and ceiling tile backing, NOT for underlayment. Available with exterior glue. Touch-sanded.	C-D PLUGGED GROUP 2 APA INTERIOR PS 1-74 000	C plugged	D	D	1/2, 19/32, 5/8, 23/32, 3/4	S-3 (1)	As Specified	Table 1 (touch-sanded)
	STRUCTURAL I or II (2) UNDERLAYMENT or C-D PLUGGED	For higher strength requirements for underlayment or built-ins. Structural I constructed from all Group 1 woods. Made with exterior glue only.	STRUCTURAL I UNDERLAYMENT APA INTERIOR PS 1-74 000 EXTERIOR GLUE	C plugged	D	C & D	1/2, 19/32, 5/8, 23/32, 3/4	S-2	Structural I Use Group 1 Structural II Use Group 3	Table 2 (touch-sanded)
	2.4.1 INT-APA	Combination subfloor-underlayment. Quality floor base. Available with exterior glue, most often touch-sanded. Available with tongue and groove.	2·4·1 T&G GROUP 2 APA INTERIOR PS 1-74 000	C plugged	D	C & D	1-1/8"	S-3 (1)	Group 1	Table 1 (touch-sanded)
	APPEARANCE GRADES	Generally applied where a high quality surface is required. Includes N-N, N-A, N-B, N-D, A-A, A-B, A-D, B-B, and B-D INT-APA Grades.	A-D GROUP 1 APA INTERIOR PS 1-74 000	B or better	D or better	D	1/4, 3/8, 1/2, 5/8, 3/4	S-3 (1)	As Specified	Table 1 (sanded)
EXTERIOR TYPE PLYWOOD	C-C EXT-APA	Unsanded sheathing grade with waterproof glue bond for wall, roof, subfloor and industrial applications such as pallet bins.	C-C 42/20 APA EXTERIOR PS 1-74 000	C	C	•C	5/16, 3/8, 1/2, 5/8, 3/4	S-1	See "Key to Identification Index"	Table 1 (unsanded)
	STRUCTURAL I C-C EXT-APA or STRUCTURAL II C-C EXT-APA (2)	"Structural" is a modifier for this unsanded sheathing grade. For engineering applications in construction and industry where full exterior-type panels are required. Structural I is made from Group 1 woods only.	STRUCTURAL I C-C 32/16 APA EXTERIOR PS 1-74 000	C	C	C	5/16, 3/8, 1/2, 5/8, 3/4	S-1	Structural I use Group 1 Structural II Use Group 3	Table 2 (unsanded)
	UNDERLAYMENT EXT-APA and C-C PLUGGED EXT-APA	Underlayment for combination subfloor-underlayment or two-layer floor under resilient floor coverings where severe moisture conditions may exist. Also for controlled atmosphere rooms and many industrial applications. Touch-sanded. Available with tongue and groove.	C-C PLUGGED GROUP 3 APA EXTERIOR PS 1-74 000	C plugged	C	C	1/2, 19/32, 23/32, 5/8, 3/4	S-2	As Specified	Table 1 (touch-sanded)
	STRUCTURAL I or II (2) UNDERLAYMENT EXT-APA or C-C PLUGGED EXT-APA	For higher strength underlayment where severe moisture conditions may exist. All Group 1 construction in *Structural I. Structural II allows Group 3 woods.*	STRUCTURAL I UNDERLAYMENT APA EXTERIOR PS 1-74 000	C plugged	C	C	1/2, 19/32, 5/8, 23/32, 3/4	S-2	Structural I Use Group 1 Structural II Use Group 3	Table 2 (touch-sanded)
	B-B PLYFORM CLASS I or II (2)	Concrete-form grade with high reuse factor. Sanded both sides, *mill-oiled unless otherwise specified.* Available in HDO. For refined design information on this special-use panel see APA publication "Plywood for Concrete Forming" (form V345). Design using values from this specification will result in a conservative design.	B-B PLYFORM CLASS I APA EXTERIOR PS 1-74 000	B	B	C	5/8, 3/4	S-2	Class I Use Group 1 Class II Use Group 3	Table 1 (sanded)
	MARINE EXT-APA	Superior Exterior type plywood made only with Douglas Fir or Western Larch. Special solid-core construction. Available with MDO or HDO face. Ideal for boat hull construction.	MARINE · A-A · EXT-APA · PS 1-74	A or B	A or B	B	1/4, 3/8, 1/2, 5/8, 3/4	A face & back use S-1 B face or back use S-2	Group 1	Table 2 (sanded)
	APPEARANCE GRADES	Generally applied where a high quality surface is required. Includes AA, A-B, A-C, B-B, B-C, HDO and MDO EXT-APA. Appearance grades may be modified to STRUCTURAL I. For such designation use Group 1 stresses and table 2 (sanded) section properties.	A-C GROUP 1 APA EXTERIOR PS 1-74 000	B or better	C or better	C	1/4, 3/8, 1/2, 5/8, 3/4	A or C face and back use S-1 B face or back use S-2	As Specified	Table 1 (sanded)

(1) When exterior glue is specified, i.e. "interior with exterior glue", stress level 2 (S-2) should be used
(2) Check local suppliers for availability of STRUCTURAL II and Plyform Class II grades.

Key to Identification Index and Species Group

For panels with "Index" as across top, and thickness as at left, use stress for species group given in table. (*)

THICKNESS (IN.)	IDENTIFICATION INDEX						
	12/0	16/0	20/0	24/0	32/16	42/20	48/24
5/16	4	3	1				
3/8		4	3	1			
1/2				4	1		
5/8					3	1	
3/4						3	1
7/8						4	3

*30/12 - 5/8", and 36/16 - 3/4" panels also sometimes available. Check your local supplier for availability. Use Group 4 stresses.

EXAMPLES OF USING SECTION PROPERTY AND ALLOWABLE STRESS TABLES

The section properties and allowable stresses presented in Tables 1 through 3 are to be used with the proper type and grade of plywood produced under U. S. Product Standard PS 1. Because the section properties must represent a wide variety of manufacturing techniques and combinations of species, they are of necessity conservative. This is especially true for the Identification Index panels. To relate plywood type and grade to Tables 1 through 3, a GUIDE TO USE OF ALLOWABLE STRESS AND SECTION PROPERTY TABLES has been provided for those grades most often used in engineering design. *See page 14.*

The proper selection of plywood type and grade will insure good performance and often produce cost savings over the improper choice. Many publications are available from the APA which contain specific recommendations for many construction applications.

The designer and specifier should bear in mind that sheathing-grade panels bear an Identification Index, and that each "Index" may be purchased in several thicknesses. Therefore, if thickness is important to a specific design, as a box beam or other component, the thickness and Identification Index should be specified. A "Key to Identification Index and Species Group" is provided to show the relation of thickness, "Index" and Species group. See above.

The following examples further illustrate the use of the "Guide" and Tables 1 through 3.

SHEATHING-GRADE EXAMPLE:

The "Guide" indicates C-D INT-APA should be used for Interior application and C-C EXT-APA is needed for exterior exposure. Both grades may be modified to the STRUCTURAL category.

For a 32/16 C-D INT-APA panel the "Guide" indicates that section properties from Table 1 should be used in conjunction with stress level three (S-3). The reader is referred to the "Key to Identification Index and Species Group". The "Key" indicates that a 32/16 Identification Index is available in 1/2" or 5/8" thickness. Selecting the 1/2" thickness indicates the use of Species Group 1. Hence, for a 1/2" 32/16 C-D INT-APA panel, the following values for stress applied parallel to the face grain are extracted from Tables 1 and 3: $I = 0.086$, $KS = 0.247$; $Ib/Q = 4.189$. Group 1 stresses in the dry condition for stress level three (S-3) are: $E = 1{,}800{,}000$, $F_b = 1650$, $F_s = 48$.

Should the panel be changed to 1/2" 32/16 C-C EXT-APA the same section properties would be used but stress level one (S-1) would be used. Stress level two (S-2) could be used with a C-D INT-APA panel if exterior glue is specified.

If STRUCTURAL I C-D INT-APA is used, the "Guide" indicates that Table 2 section properties should be used along with level two (S-2) stresses. For a 1/2" STRUCTURAL I C-D INT-APA panel the following section properties are obtained: $I = 0.091$, $KS = 0.318$, $Ib/Q = 4.497$ where stress is applied parallel to the face grain. Should the stress be applied perpendicular to the face grain, the following section properties should be used: $I = 0.017$, $KS = 0.145$, $Ib/Q = 2.574$.

SANDED-PANEL EXAMPLE:

Plywood produced with an A or B face is generally fully sanded and considered an appearance grade. For a 3/4" Group 3 B-C EXT-APA panel the "Guide" indicates that stress level two (S-2) should be used. The "Guide" also shows that the sanded portion of Table 1 should be used to obtain section properties; they are: $I = 0.197$, $KS = 0.452$ and $Ib/Q = 7.881$ for stress applied parallel to the face. The allowable stresses for the wet condition are: $F_b = 820$, $F_s = 44$, and $E = 1{,}100{,}000$.

TOUCH-SANDED EXAMPLE:

Plywood manufactured as UNDERLAYMENT, C-D Plugged or C-C Plugged is generally touch-sanded. To find the properties and stresses for a 19/32-in. Group 1 UNDERLAYMENT EXT-APA, the guide indicates level two (S-2) stresses should be used with Table 1 section properties. The section properties are: $I = 0.123$, $KS = 0.337$, $Ib/Q = 5.403$ Group 1 stresses in the dry condition for stress level two (S-2) would be: $F_b = 1650$, $E = 1{,}800{,}000$, $F_s = 53$. If STRUCTURAL I UNDERLAYMENT EXT-APA is specified the same stresses are used except $F_s = 75$. However, the "Guide" indicates Table 2 should be used for section properties. For 19/32-in. STRUCTURAL I UNDERLAYMENT EXT-APA the section properties are: $I = 0.124$, $KS = 0.349$, Ib/Q - 6.094.

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EFFECTIVE SECTION PROPERTIES FOR PLYWOOD

Table 1. Face Plies of Different Species Group from Inner Plies (Includes all Product Standard Grades except those noted in Table 2.)

			STRESS APPLIED PARALLEL TO FACE GRAIN				STRESS APPLIED PERPENDICULAR TO FACE GRAIN			
1 NOMINAL THICKNESS (in.)	2 APPROXIMATE WEIGHT (psf)	3 EFFECTIVE THICKNESS FOR SHEAR (in.)	4 A AREA (in.²/ft)	5 I MOMENT OF INERTIA (in.⁴/ft)	6 KS EFF. SECTION MODULUS (in.³/ft)	7 Ib/Q ROLLING SHEAR CONSTANT (in.²/ft)	8 A AREA (in.²/ft)	9 I MOMENT OF INERTIA (in.⁴/ft)	10 KS EFF. SECTION MODULUS (in.³/ft)	11 Ib/Q ROLLING SHEAR CONSTANT (in.²/ft)
UNSANDED PANELS										
5/16-U	1.0	0.283	1.914	0.025	0.124	2.568	0.660	0.001	0.023	–
3/8 -U	1.1	0.293	1.866	0.041	0.162	3.108	0.799	0.002	0.033	–
1/2 -U	1.5	0.316	2.500	0.086	0.247	4.189	1.076	0.005	0.057	2.585
5/8 -U	1.8	0.336	2.951	0.154	0.379	5.270	1.354	0.011	0.095	3.252
3/4 -U	2.2	0.467	3.403	0.243	0.501	6.823	1.632	0.036	0.232	3.717
7/8 -U	2.6	0.757	4.109	0.344	0.681	7.174	2.925	0.162	0.542	5.097
1 -U	3.0	0.859	3.916	0.493	0.859	9.244	3.611	0.210	0.660	6.997
1-1/8 -U	3.3	0.877	4.621	0.676	1.047	10.008	3.464	0.307	0.821	8.483
SANDED PANELS										
1/4 -S	0.8	0.278	1.307	0.009	0.067	2.182	0.681	0.001	0.018	–
3/8 -S	1.1	0.294	1.307	0.027	0.125	3.389	1.181	0.004	0.053	–
1/2 -S	1.5	0.450	1.947	0.077	0.266	4.834	1.281	0.018	0.150	3.099
5/8 -S	1.8	0.472	2.280	0.129	0.356	6.293	1.627	0.045	0.234	3.922
3/4 -S	2.2	0.589	2.884	0.197	0.452	7.881	2.104	0.093	0.387	4.842
7/8 -S	2.6	0.608	2.942	0.278	0.547	8.225	3.199	0.157	0.542	5.698
1 -S	3.0	0.846	3.776	0.423	0.730	8.882	3.537	0.253	0.744	7.644
1-1/8 -S	3.3	0.865	3.854	0.548	0.840	9.883	3.673	0.360	0.918	9.032
TOUCH-SANDED PANELS										
1/2 -T	1.5	0.346	2.698	0.083	0.271	4.252	1.159	0.006	0.061	2.746
19/32 -T	1.7	0.491	2.618	0.123	0.337	5.403	1.610	0.019	0.150	3.220
5/8 -T	1.8	0.497	2.728	0.141	0.364	5.719	1.715	0.023	0.170	3.419
23/32 -T	2.1	0.503	3.181	0.196	0.447	6.600	2.014	0.035	0.226	3.659
3/4 -T	2.2	0.509	3.297	0.220	0.477	6.917	2.125	0.041	0.251	3.847
2-4-1 1-1/8 -T	3.3	0.855	4.592	0.653	0.995	9.933	4.120	0.283	0.763	7.452

Table 2. Structural I, II and Marine

			STRESS APPLIED PARALLEL TO FACE GRAIN				STRESS APPLIED PERPENDICULAR TO FACE GRAIN			
1 NOMINAL THICKNESS (in.)	2 APPROXIMATE WEIGHT (psf)	3 EFFECTIVE THICKNESS FOR SHEAR (in.)	4 A AREA (in.²/ft)	5 I MOMENT OF INERTIA (in.⁴/ft)	6 KS EFF. SECTION MODULUS (in.³/ft)	7 Ib/Q ROLLING SHEAR CONSTANT (in.²/ft)	8 A AREA (in.²/ft)	9 I MOMENT OF INERTIA (in.⁴/ft)	10 KS EFF. SECTION MODULUS (in.³/ft)	11 Ib/Q ROLLING SHEAR CONSTANT (in.²/ft)
UNSANDED PANELS										
5/16 - U	1.0	0.356	2.375	0.025	0.144	2.567	1.188	0.002	0.029	–
3/8 - U	1.1	0.371	2.226	0.041	0.195	3.107	1.438	0.003	0.043	–
1/2 - U	1.5	0.543	2.906	0.091	0.318	4.497	2.325	0.017	0.145	2.574
5/8 - U	1.8	0.609	3.464	0.157	0.437	5.993	2.925	0.052	0.267	3.238
3/4 - U	2.2	0.747	4.406	0.247	0.573	7.046	2.938	0.085	0.369	3.697
7/8 - U	2.6	0.776	4.388	0.346	0.690	6.948	3.510	0.192	0.584	5.086
1 - U	3.0	1.088	5.200	0.529	0.922	8.512	6.500	0.366	0.970	6.986
1-1/8 - U	3.3	1.119	6.654	0.751	1.164	9.061	5.542	0.503	1.131	8.675
SANDED PANELS										
1/4 -S	0.8	0.342	1.680	0.013	0.092	2.172	1.226	0.001	0.027	–
3/8 -S	1.1	0.373	1.680	0.038	0.177	3.382	2.126	0.007	0.078	–
1/2 -S	1.5	0.545	1.947	0.078	0.271	4.816	2.305	0.030	0.217	3.076
5/8 -S	1.8	0.717	3.112	0.131	0.361	6.526	2.929	0.077	0.343	3.887
3/4 -S	2.2	0.748	3.848	0.202	0.464	7.926	3.787	0.162	0.570	4.812
7/8 -S	2.6	0.778	3.952	0.298	0.569	7.539	5.759	0.275	0.798	5.671
1 -S	3.0	1.091	5.215	0.479	0.827	7.978	6.367	0.445	1.098	7.639
1 - 1/8 -S	3.3	1.121	5.593	0.623	0.955	8.840	6.611	0.634	1.356	9.031
TOUCH-SANDED PANELS										
1/2 -T	1.5	0.543	2.698	0.084	0.282	4.580	2.486	0.020	0.162	2.720
19/32 -T	1.7	0.707	3.127	0.124	0.349	6.094	2.899	0.050	0.259	3.183
5/8 -T	1.8	0.715	3.267	0.144	0.378	6.552	3.086	0.060	0.293	3.383
23/32 -T	2.1	0.739	4.059	0.201	0.469	6.971	3.625	0.078	0.350	3.596
3/4 -T	2.2	0.746	4.209	0.226	0.503	7.379	3.825	0.092	0.388	3.786

Table 3. Allowable Stresses for Plywood.

Conforming to U.S. Product Standard PS-1-74 for Construction and Industrial Plywood. Normal Load Basis in PSI.

TYPE OF STRESS		SPECIES GROUP of FACE PLY	GRADE STRESS LEVEL *				
			S-1 WET	*S-1* DRY	*S-2* WET	*S-2* DRY	*S-3* DRY ONLY
EXTREME FIBER STRESS IN BENDING (F_b)	F_b & F_t	1	1430	2000	1190	1650	1650
TENSION IN PLANE OF PLIES (F_t)		2, 3	980	1400	820	1200	1200
Face Grain Parallel or Perpendicular to Span		4	940	1330	780	1110	1110
(At 45° to Face Grain Use 1/6 F_t)							
COMPRESSION IN PLANE OF PLIES. (F_c).	F_c	1	970	1640	900	1540	1540
Parallel or Perpendicular to Face Grain		2	730	1200	680	1100	1100
		3	610	1060	580	990	990
(At 45° to Face Grain Use 1/3 F_c)		4	610	1000	580	950	950
SHEAR IN PLANE PERPENDICULAR TO PLIES	F_v	1	205	250	205	250	210
Parallel or Perpendicular to Face Grain		2,3	160	185	160	185	160
(At 45° to Face Grain Use 2 F_v)		4	145	175	145	175	155
SHEAR, ROLLING, IN THE PLANE OF PLIES	F_s	MARINE and STRUCTURAL I	63	75	63	75	
Parallel or Perpendicular to Face Grain		STRUCTURAL II and 2-4-1	49	56	49	56	55
(At 45° to Face Grain Use 1 1/3 F_s)		ALL OTHER	44	53	44	53	48
MODULUS OF RIGIDITY	G	1	70,000	90,000	70,000	90,000	82,000
Shear in Plane Perpendicular to Plies		2	60,000	75,000	60,000	75,000	68,000
		3	50,000	60,000	50,000	60,000	55,000
		4	45,000	50,000	45,000	50,000	45,000
BEARING (ON FACE)	$F_{c\perp}$	1	210	340	210	340	340
Perpendicular to Plane of Plies		2,3	135	210	135	210	210
		4	105	160	105	160	160
MODULUS OF ELASTICITY IN BENDING IN PLANE OF PLIES.	E	1	1,500,000	1,800,000	1,500,000	1,800,000	1,800,000
Face Grain Parallel or Perpendicular to Span		2	1,300,000	1,500,000	1,300,000	1,500,000	1,500,000
		3	1,100,000	1,200,000	1,100,000	1,200,000	1,200,000
		4	900,000	1,000,000	900,000	1,000,000	1,000,000

* See page 14 for Guide.

To qualify for stress level S-1, gluelines must be exterior and only veneer grades N, A, and C are allowed in either face or back.

For stress level S-2, gluelines must be exterior and veneer grade B, C-plugged and D are allowed on the face or back.

Stress level S-3 includes all panels with interior or intermediate glue lines.

3.1.2 Grade Stress Level

The allowable stresses presented in Table 3 are divided into three levels which are related to grade. Plywood with exterior glue, and with face and back plies containing only N, A, or C veneers, shall use level one (S-1) stresses. Plywood of Exterior type or Interior type with exterior glue, and with B, C-plugged or D veneers in either face or back, shall use level two (S-2) stresses. All grades with interior or intermediate glue shall use level three (S-3) stresses.

The Guide to Table Use supplies direct relationship between Tables 1 through 3 and most plywood grades. The Table of Allowable Stresses is based on research indicating that strength is directly related to veneer grade and glue type.

The derivation of the stress levels is as follows: Bending, tension, and compression stresses depend on the grade of the veneers. Since veneer grades N, A, and C are the strongest, panels composed entirely of these grades have higher allowable stresses than panels with any veneers of B, C-plugged, or D. Although veneer grades B and C-plugged are superior in appearance to C, they rate a lower stress level, because the "plugs" and "patches" which improve their appearance reduce their strength somewhat. For these "direct" stresses, therefore, panel type, Interior or Exterior, is important, as panel type determines grade of inner plies.

Shear stresses, on the other hand, do not depend on veneer grade, but do vary with kind of glue. (Therefore, as an illustration, if available, an N-N grade panel with N face and back and inner plies of C veneers, but with interior glue, would qualify for the higher bending, tension, and compression stresses, but for the lower shear values.)

Stiffness and bearing strength do not depend either on glue or on veneer grade, but on species group.

3.2 SERVICE MOISTURE CONDITIONS

Table 3 lists allowable stresses for both wet and dry moisture conditions. The use of these stresses shall be as defined in this Section.

3.2.1 Dry Conditions

The allowable stresses in the columns titled "dry" in Table 3, and adjustments thereof, apply to plywood under conditions which are continuously dry. Dry conditions are defined in this Specification as involving an equilibrium moisture content of less than 16%.

3.2.2 Wet Conditions

When equilibrium moisture content in service will be 16% or greater, as in applications that are directly exposed to the weather, the allowable stresses in Table 3 under the columns titled "wet" shall be used. Use Exterior-type plywood where equilibrium moisture content will be greater than 18%.

3.3 MODIFICATION OF STRESSES

3.3.1 Duration of Loading

The allowable unit stresses in Table 3 are for normal duration of load, and are applicable to all conditions other than those for which specific exceptions are made. *Normal duration of load* contemplates fully stressing a member by the application of the full maximum design load, either continuously or cumulatively, for a duration of approximately ten years.

Allowable stresses shall be adjusted for duration of loading. These adjustments also apply to mechanical fasteners, but not to modulus of elasticity.

For a more detailed explanation of adjustments for duration of load, see NATIONAL DESIGN SPECIFICATION FOR STRESS-GRADE LUMBER AND ITS FASTENINGS, National Forest Products Association, Washington, D.C. or U.S. Forest Products Laboratory report R1916.

3.3.1.1 Load Duration Less than Normal— When the duration of the full maximum load does not exceed the period indicated, increase the allowable stresses in Table 3 as follows:

15% for two months' duration, as for snow
25% for seven days' duration
33 1/3% for wind or earthquake
100% for impact

Allowable stresses given in Table 3 for normal loading conditions may be used without regard to impact if the stress induced by impact does not exceed the allowable unit stress for normal duration of load.

The above increases are not cumulative. The resulting structural sections shall not be smaller than required for a longer-duration loading.

3.3.1.2 Permanent Duration of Load—Where a member is fully stressed to the maximum allowable stress for more than 10 years either continuously or cumulatively under the condition of maximum design load, use working stresses 90% of those in Table 3.

3.3.2 Pressure Treatment

Allowable stresses for pressure-treated plywood shall be adjusted as described in this Section. The resulting stresses are subject to further adjustments for duration of load and moisture content, as set forth in Sections 3.2 and 3.3.

3.3.2.1 Preservative Treatment—The allowable stresses in Table 3 apply to plywood pressure-impregnated with preservative chemicals in accordance with American Wood Preservers Association (AWPA) Specification C-9 or American Wood Preservers Bureau (AWPB) Treatment Standard FDN.

3.3.2.2 Fire-Retardant Treatment—The allowable stresses in Table 3 shall be reduced 1/6th, and modulus of elasticity shall be reduced 1/10th for plywood pressure-impregnated with fire-retardant chemicals in accordance with AWPA Specification C-27.

3.3.3 Panel Size

The allowable stresses in bending (F_b), tension (F_t) and compression (F_c) given in Table 3 are appropriate for panels greater than 24 inches in width. For small, highly stressed pieces of plywood there is an increased possibility of having a random strength-reducing defect in a critical section. A reduction in allowable stresses therefore is recommended for applications where human life may be endangered by failure of a single piece of plywood, such as scaffold planking, or a highly stressed gusset plate. In such cases, a reduction in F_b, F_t, and F_c should be applied to plywood strips in proportion to their width, commencing with no reduction at 24" and ranging to 50% at 8" and less. Single strips less than 8" used in stressed applications should be chosen such that they are relatively free of surface defects.

Development of the allowable stresses is based on plywood panels at least 24 inches in width. On the other hand, plywood has historically performed well in smaller sizes such as narrow panels for roof sheathing, shelving, rigid frames, pallet bins, and gussets for trusses. The designer should consider that with a small piece of plywood a defect allowed in the grade will have a greater effect, especially if it is located in an area of high stress. Also the chance that a significant strength-reducing defect will occur in a highly stressed area decreases as the number of parallel plies increases. Thus, a 5-ply panel should be superior to a 3-ply panel. The reduction is intended only for applications which would endanger human life. For critical applications culling of pieces with surface defects is recommended.

3.4 MODULUS OF ELASTICITY

Moduli of elasticity (MOE or E) presented in Table 3 shall be used for all grades of plywood, except where modified as required in Section 3.2 and 3.3. Modulus of elasticity for the species group of the face ply is to be used, in both parallel and perpendicular directions. When shear deflection is computed separately from bending deflection, the modulus of elasticity shall be increased by ten percent in calculating the bending deflection.

The modulus of elasticity listed in Table 3 is an effective modulus including an allowance for average shear deflection. Plywood sheathing is generally used in applications where the loads are considered to be uniformly distributed and where the spans are normally from 30 to 50 times the thickness of the plywood. Tests have shown that shear deformation accounts for only a small percentage of the total deflection occurring at these span-to-depth (l/d) ratios.

Because the test data on which the tables are based include a shear-deflection component of approximately ten percent, the tabulated modulus of elasticity value itself contains an adequate allowance for the shear deflection that occurs in most applications.

In certain cases, however, where short spans are involved (l/d from 15 to 20, or lower) deflections computed using the tabulated modulus of elasticity will tend to underestimate total actual deflection. In such cases, the shear deflection should be calculated separately and added to the bending deflection. The recommended shear deflection formula is given in Section 4.1.3.2.

Bending deflection in these cases should be calculated by the conventional formulas, using a true modulus of elasticity in bending, which is 1.1 times the tabulated effective modulus of elasticity shown in Table 3.

3.5 PLYWOOD STRESSED IN BENDING

The allowable stresses for extreme fiber in bending (F_b) from Table 3 shall be chosen with proper regard for plywood grade, as noted in Section 3.1.2; for service moisture conditions as in Section 3.2 and for duration of load as in 3.3. The allowable stress in bending for the species group of the face ply shall be used, for stress applied either parallel or perpendicular to the face grain.

3.5.1 Load Applied Perpendicular to the Plane of the Panel

When the loads are applied perpendicular to the plane of the panel, the allowable bending stresses shall be used with section-modulus values (KS) from Tables 1 and 2; not with values for moment of inertia.

3.5.2 Loads Applied Parallel to the Plane of the Panel

Where end joints occur, the allowable stresses in bending shall be modified as provided in Section 5.6.

Figure 3.1 Plywood in bending. Load applied perpendicular to the plane of the panel (A) and parallel to the plane of the panel (B).

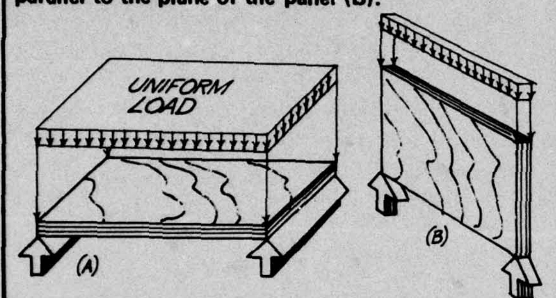


Figure 3.1 indicates the direction of loading relative to the plane of the plywood panel as specified in this Section. For computing section properties of plywood used vertically as in Figure 3.1(B) and for the design of such applications, as in box beams, see PDS Supplement 2. For recommendations on designing plywood beams with laminated webs see Research Report Number 124 available from APA.

3.6 PLYWOOD STRESSED IN TENSION OR COMPRESSION

The allowable stresses for tension in the plane of the plies (F_t) and compression in the plane of the plies (F_c) from Table 3 shall be modified for plywood grades as noted in Section 3.1.2, for service moisture as in Section 3.2 and for duration of load as in 3.3. The allowable stress for the species group of the face shall be used for stress applied either parallel or perpendicular to the face grain, with the appropriate area from Tables 1 and 2. The use of these allowable stresses is further restricted as set forth in this Section.

3.6.1 Allowable Stresses in Axial Tension

The allowable stress for tension in Table 3 shall be applied to the area from Column 4 of Tables 1 and 2 when the stress is applied in the direction of the face grain. The same allowable stress shall be applied to the area from Column 8 of Tables 1 and 2 for tension stress applied perpendicular to the face grain.

3.6.2 Allowable Stresses in Axial Compression

The allowable stress for compression in Table 3 shall be applied to the area from Column 4 of Tables 1 and 2 when the stress is applied in the direction of the face grain. The same allowable stress shall be applied to the area from Column 8 of Tables 1 and 2 for compression stress applied perpendicular to the face grain.

3.6.3 Tension or Compression at Angles to the Face Grain

See Italicized section below for angles other than 45 degrees.

3.6.3.1 Tension at 45 Degrees to the Face Grain— The allowable stresses for tension at 45 degrees to the face grain shall be as given in Table 3. The value may be applied to the full thickness of the panel if all plies are of the same species group, as in STRUCTURAL I. If the inner plies are not of the same species group, total area must be adjusted in proportion to the actual moduli of elasticity and actual area of all plies.

3.6.3.2 Compression at 45 Degrees to the Face Grain— The allowable stresses for compression at 45 degrees to the face grain shall be as given in Table 3. They may be applied to the full thickness of the panel if all plies are of the same species group, as in STRUCTURAL I. If the inner plies are not of the same species group, total area must be adjusted.

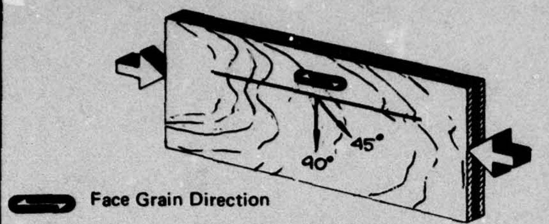
For tension or compression parallel or perpendicular to the face grain, section properties have been adjusted so that allowable stress for the species group of the faces may be applied to the area given in Tables 1 and 2. Thus, no additional correction need be made for species group of inner plies.

For tension or compression stress applied at 45^o to the face grain, allowable stresses from Table 3 may be applied to the full thickness under consideration if all plies are of the same species group as the face. If the inner plies are not of the same species group, an adjusted area may be approximated by using 70% of the gross cross section.

For angles between 0^o (direction of the face grain) and 45^o, an approximate solution may be obtained by straight-line interpolation between the product of area and stress for the parallel direction and the

similar product for 45° to the face grain. For angles between 45° and 90° to the face grain, a similar approximate solution may be obtained by straight-line interpolation between the product of area and stress for 45° to the face grain and the product of area and stress for 90° (perpendicular to the face grain). Figure 3.2 details the directions for axial loads in the plane of the plies.

Figure 3.2 Axial loads in the plane of the plies. Face grain assumed to be zero degrees.



3.7 PLYWOOD STRESSED IN BEARING ON THE FACE

Allowable stresses for bearing on the face ($F_c\perp$) from Table 3 shall be used for all plywood grades, modified as required in Sections 3.2 and 3.3. The allowable stress for the species group of the face shall be used.

3.8 PLYWOOD STRESSED IN SHEAR

Due to the cross-laminated construction of plywood, two different types of shear must be considered.

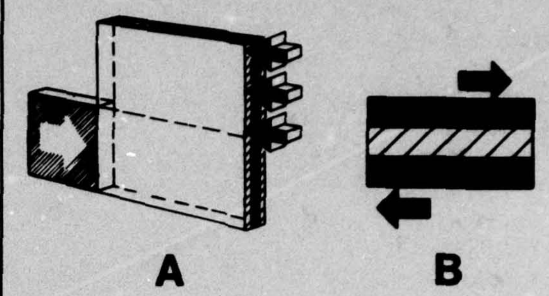
3.8.1 Allowable Stresses for Shear in Planes Perpendicular to the Plies

Allowable stresses for shear in a plane perpendicular to the plies (shear-through-the-thickness) (F_v) shall be as given in Table 3, modified as required in Section 3.2 and 3.3. The allowable stresses shall be used for plywood grades as noted in Section 3.1.2 and shall be for the species group of the face ply. The allowable stresses shall be applied to the appropriate thickness in Column 3 of Tables 1 and 2. For shear imposed at 45° to the face grain, the allowable stress may be increased 100%.

Shear-through-the-thickness stresses in Table 3 are based on the most common structural applications, where the plywood is attached to framing around its boundary. If the plywood is attached to framing at only two sides–as in the heel joint of a truss–allowable shear-through-the-thickness values shall be multiplied by 89% where the framing is parallel to the face grain and 75% where it is perpendicular to the face grain. Shear-through-the-thickness values shall also be used for "punching shear" calculations.

See figure 3.3(A) for an illustration of shear in a plane perpendicular to the plies.

Figure 3.3 The two types of shear in plywood. Typical shear-through-the-thickness (A) and shear in the plane of the plies or rolling shear (B).



3.8.2 Allowable Stresses for Shear in the Plane of the Plies (Rolling Shear).

The allowable stresses given in Table 3 for rolling shear (F_s) shall be used for shear in the plane of the plies, modified as required in Section 3.3. The allowable stress shall be applied to the contact area under stress. For certain applications involving stress concentrations, allowable stress shall be reduced 50%. Such applications include the outside stringer of stressed-skin panels, and the flange-to-web joint in box beams. If the rolling shear is imposed at an angle of 45° to the face grain, the allowable stress may be increased by 1/3.

See Figure 3.3(B) for an illustration of rolling shear. Since some of the plies in plywood are at right angles to others, certain types of loading subject them to stresses which tend to make them roll, and a "rolling-shear" stress is induced. The allowable stresses presented in Table 3 apply to most cases of rolling-shear stress, except where the stressed area occurs at the edge of a panel, so that stress concentrations may occur. For applications where such stress concentrations are expected, it is conventional to reduce allowable design rolling-shear stresses by 50% due to an imbalance of stress on the total area under consideration. Methods for handling plywood component design are included as Supplements to this Specification or in American Plywood Association Design Methods. These design methods indicate where such reductions are necessary, and include means for implementing them.

3.9 SPECIFICATIONS AND PLANS

When plywood is used structurally, specifications and plans should accurately designate grades required for

each application. They should require that the plywood conform with U. S. Product Standard PS 1 and bear the APA grade-trademark of the American Plywood Association. They should be prepared using stresses and section properties in accordance with this PLYWOOD DESIGN SPECIFICATION and design methods in accordance with this Specification and its Supplements, and should so state.

The following design methods are currently available as supplements:

SUPPLEMENT 1 DESIGN OF PLYWOOD CURVED PANELS

SUPPLEMENT 2 DESIGN OF GLUED PLYWOOD BEAMS

SUPPLEMENT 3 DESIGN OF PLYWOOD STRESSED-SKIN PANELS

SUPPLEMENT 4 DESIGN OF PLYWOOD SANDWICH PANELS

The following plywood design methods will be included as Supplements to this document as soon as practical. They are now available separately from the American Plywood Association:

PLYWOOD FOLDED PLATES, DESIGN AND DETAILS, RESEARCH REPORT 121

PLYWOOD DIAPHRAGM CONSTRUCTION

4. DESIGN LOADS AND DESIGN FORMULAS

Design loads for mechanical fasteners, and allowable stresses for stress-grade lumber, shall be as given in the latest edition of the NATIONAL DESIGN SPECIFICATION FOR STRESS-GRADE LUMBER AND ITS FASTENINGS, National Forest Products Association, Washington, D. C.

Design formulas shall be as given in this PLYWOOD DESIGN SPECIFICATION and its Supplements, or otherwise according to accepted engineering practice.

4.1 UNIFORM LOADS FOR PLYWOOD

Computation of uniform-load capacity of plywood panels shall be as outlined in this section for such applications as roofs, floors and walls. The allowable stresses are subject to modification as specified in Section 3.

Three basic span conditions are presented for computing uniform-load capacities of plywood. For normal framing practice and a standard plywood panel size (4'x8') the APA has used the following assumptions in computing recommendations for load-span tables. When the face grain is across (perpendicular to) the supports, the three-span condition is used for support spacing up to and including 32 inches. The two-span condition is assumed for support spacing greater than 32 inches.

When plywood face grain is placed parallel to the supports the three-span condition is assumed for support spacing up to and including 16 inches; the two-span condition is assumed for face grain parallel to supports when the support spacing is 24 inches, and the single-span condition is used for spans greater than 24 inches. Four-inch-nominal framing is assumed for support spacing of 48 inches or greater.

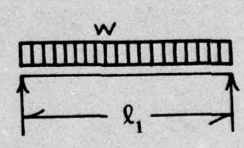
The equations presented in this section are standard beam formulas altered to accept the mixed units noted. These formulas are provided for computing uniform loads on plywood over conventional framing. They assume one-way "beam" action, rather than two-way, or "slab" action. (Some work has been done on two-way action with plywood, but final results are not available.) The resulting loads are assumed to be applied to full-sized panels in standard sheathing-type applications. Loads are for the plywood only, and in no way account for the design of the framing supports. Further consideration should be given to concentrated loads, in compliance with local building codes and with published recommendations of the American Plywood Association.

4.1.1 Uniform Loads Based on Bending Stress

The following formulas shall be used for computing loads based on allowable bending stress (F_b).

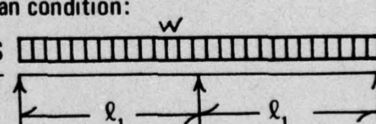
For a single span:

$$w_b = \frac{96\ F_b\ KS}{\ell_1^{\,2}}$$



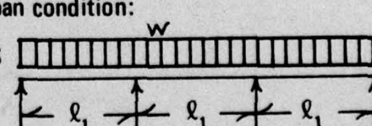
For a two-span condition:

$$w_b = \frac{96\ F_b\ KS}{\ell_1^{\,2}}$$



For a three-span condition:

$$w_b = \frac{120\ F_b\ KS}{\ell_1^{\,2}}$$



Where: F_b = allowable bending stress (psi)
KS = effective section modulus (in.^{3}/ft)
ℓ_1 = span center-to-center of supports (in.)
w_b = uniform load based on bending stress (psf)

4.1.2 Uniform Loads Based on Shear Stress

The following formulas shall be used for computing loads based on allowable shear stress (F_s). Span conditions are as shown in Section 4.1.1 and symbols are the same unless otherwise noted.

For a single span:

$$w_s = \frac{24\ F_s\ (Ib/Q)}{\ell_2}$$

For a two-span condition:

$$w_s = \frac{19.2\ F_s\ (Ib/Q)}{\ell_2}$$

For a three-span condition:

$$w_s = \frac{20\ F_s\ (Ib/Q)}{\ell_2}$$

Where: F_s = allowable rolling-shear stress (psi)
Ib/Q = rolling shear constant (in.^{2}/ft)
ℓ_2 = clear span (in.) (center-to-center span minus support width)
w_s = uniform load based on shear stress (psf)

4.1.3 Uniform Loads Based on Deflection Requirements

The following formulas shall be used for computing deflection under uniform load, or allowable loads based on deflection requirements.

4.1.3.1 Bending Deflection—The following formulas are used to compute deflection due to bending. For most cases, as described in Section 3.4, a single calculation is sufficient, using these equations and the effective moduli of elasticity listed in Table 3. For cases where shear deflection is computed separately, and added to bending deflection to obtain total deflection, E for these bending-deflection equations should be increased 10%.

For a single-span:

$$\Delta_b = \frac{w\ell_3^{\ 4}}{921.6\ EI}$$

For a two-span condition:

$$\Delta_b = \frac{w\ell_3^{\ 4}}{2220\ EI}$$

For a three-span condition:

$$\Delta_b = \frac{w\ell_3^{\ 4}}{1743\ EI}$$

where Δ_b = bending deflection (in.)
w = uniform load (psf)
E = modulus of elasticity (psi)
I = effective moment of inertia (in.^{4}/ft)
ℓ_3 = clear span + SW
SW = *support-width factor*, equal to 0.25" for two-inch nominal framing and 0.625" for four-inch nominal framing. For additional information on this factor see APA Research Report Number 120.

4.1.3.2 Shear Deflection—The shear deflection may be closely approximated for all span conditions by the following formula:

$$\text{where: } \Delta_s = \frac{wCt^2\ell_2^{\ 2}}{1270\ EI}$$

where: Δ_s = shear deflection (in.)
w = uniform load (psf)
C = constant, equal to 120 for panels applied with face grain perpendicular to supports and 60 for panels with face grain parallel to supports.
t = nominal panel thickness (in.)
E = modulus of elasticity unadjusted (psi)
I = effective moment of inertia (in.^{4}/ft)

4.1.3.3 Uniform Load—For uniform load based on a deflection requirement, compute bending deflection and shear deflection (if desired) with a uniform load (w) equal to one psf. The allowable uniform load based on the allowable deflection is then computed as:

$$w_d = \frac{\Delta_{all.}}{\Delta_b + \Delta_s}$$

where: w_d = uniform load for deflection (psf)
$\Delta_{all.}$ = allowable deflection (in.)

5. DESIGN OF RIGIDLY GLUED PLYWOOD-LUMBER STRUCTURAL ASSEMBLIES

This Section deals solely with rigidly glued assemblies where the adhesive unites the plywood and lumber, if used, into a single unit. No provision of this section should be interpreted to preclude use of adhesives simply to add stiffness to a unit designed as mechanically fastened.

5.1 DESIGN METHODS

The provisions of this section should be used in conjunction with design methods for specific components, as given in Supplements to this Specification, or, if a Supplement is not available for a component, with the Design Method published by the American Plywood

Association. Other design methods may be employed, provided they are supported by adequate test data or rational analysis.

5.2 FABRICATION SPECIFICATIONS

This Specification applies to the design of structural assemblies of plywood and lumber that will be carefully fabricated in accordance with good practice, employing materials and workmanship of good quality. For best assurance of quality, they shall be subject to the inspection of a qualified agency. The following fabrication specifications, published by the American Plywood Association, define good practice.

1) Fabrication of Plywood Curved Panels – CP-8
2) Fabrication of Plywood Beams – BB-8
3) Fabrication of Plywood Stressed-Skin Panels – SS-8
4) Fabrication of Plywood Sandwich Panels – SP-61
5) Fabrication of Plywood Folded Plates – FP-69
6) Fabrication of Trussed Rafters with Plywood Gussets – GT-8

5.2.1 "Structural Glued Laminated Timber"

"Structural Glued Laminated Timber" shall be fabricated in accordance with the current edition of U.S. Product Standard PS 56 for STRUCTURAL GLUED LAMINATED TIMBER.

5.3 ADHESIVES

Adhesives for plywood-lumber structural assemblies should provide both stiffness and strength to the assembly. The adhesives used for this purpose shall be as defined in this Section.

5.3.1 Interior (Dry) Exposure

When the moisture content of the assembly does not continuously or repeatedly exceed 18%, water-resistant adhesives, such as casein glue, may be specified for assembly gluing.

5.3.2 Exterior (Wet) Exposure

When the moisture content of the assembly continuously or repeatedly exceeds 18%, as when exposed to the weather, exterior type adhesives, such as phenol and resorcinol resins shall be specified for assembly gluing. Some epoxies, if specifically formulated for wood, may meet exterior performance requirements.

5.4 PLYWOOD FOR STRUCTURAL ASSEMBLIES

5.4.1 Classification

Type and grade of plywood used in structural assemblies shall be specified as covered in Sections 1.3 and 1.4 of this specification.

5.4.2 Allowable Stresses for Plywood

The stiffness and allowable unit stresses shall be applied for the proper type and grade as specified in Section 3 of this Specification. Additional modification of stresses may be required as defined in Sections 5.4.5 and 5.4.6.

Where plywood is bonded into multiple layers and used in strips, as ridge beams for mobile homes, the resulting member may be stronger than a single sheet, due to randomization of defects. In such a case, allowable stresses could be higher than given in Table 3 when the particular application has been demonstrated.

5.4.3 Section Properties for Plywood

The section properties of plywood shall be applied for the proper type and grade as specified in Section 2 of this Specification.

5.4.4 Shear Deflection

When the shear deflection of an assembly having plywood flanges (such as a stressed-skin panel) is calculated separately and added to the bending deflection, the elastic modulus of the plywood, given in Table 3, may be increased 10%.

5.4.5 Radial Tension

For plywood used in curved assemblies where radial tension stresses will occur, the tension stress shall not exceed one-half the allowable stress in rolling shear as defined in Section 3.

5.4.6 Radial Compression

For plywood used in curved assemblies where radial compression stress will occur, the compression stress shall not exceed the allowable stress in bearing, as defined in Section 3.

For plywood used in curved assemblies, the recommended minimum radii of curvature are given in Appendix A2.

5.5 LUMBER FOR STRUCTURAL ASSEMBLIES

5.5.1 Classification

Lumber for use in plywood structural assemblies shall fall into one of the following two categories.

5.5.1.1 Stress-Grade Lumber—Stress-grade lumber is defined in this Specification as lumber conforming with standard stress-grading rules, and so identified by a qualified grading agency, but not subject to the additional restrictions imposed on glued-laminated lumber. Even if laminated, it is still defined as stress-grade lumber.

5.5.1.2 "Structural Glued Laminated Timber"—For purposes of this Specification, lumber may be classed as "Structural Glued Laminated Timber" when it conforms with the latest edition of STANDARD SPECIFICATIONS FOR STRUCTURAL GLUED LAMINATED TIMBER, AITC 117 and AITC 120 as published by the American Institute of Timber Construction (AITC).

5.5.2 Allowable Stresses for Lumber

5.5.2.1 Stress-Grade Lumber— Allowable stresses and modifications thereof shall be as defined in the latest edition of NATIONAL DESIGN SPECIFICATION FOR STRESS-GRADE LUMBER AND ITS FASTENINGS, National Forest Products Association. Stress-grade lumber does not qualify for structural glued laminated timber stresses, regardless of the number of laminations.

5.5.2.2 "Structural Glued Laminated Timber"—Allowable stresses for "Structural Glued Laminated Timber" and modifications thereof shall be as defined in the latest edition of STANDARD SPECIFICATIONS FOR STRUCTURAL GLUED LAMINATED TIMBER, AITC 117 and AITC 120.

5.5.2.3 Number of Laminations for Determining Allowable Stress Level—The number of laminations to be used in determining the allowable stress level of a laminated member shall include all lumber laminations of appropriate grade that are subjected to the principal stress, but shall not include plywood webs or plywood shims within the member. Lumber shims, if appropriately graded, may be grouped to equal or exceed the lamination thickness, and the group considered as a lamination. Similarly, in a member where laminations are ripped diagonally (as in some folded-plate chords) ripped portions of laminations may be paired to equal or exceed the full lamination width, and the pair considered as a lamination.

5.5.2.4 Number of Laminations for Resisting Stress—All laminations, including webs and shims, may be considered as resisting stress with due consideration for grade and end joints.

5.5.3 Adjustments for Service Moisture Conditions

5.5.3.1 Stress-Grade Lumber— Allowable stresses for stress-grade lumber shall be modified for in-use moisture content of the lumber as set forth in the latest edition of NATIONAL DESIGN SPECIFICATION FOR STRESS-GRADE LUMBER AND ITS FASTENINGS.

5.5.3.2 Structural Glued Laminated Timber—Allowable stresses for Structural Glued Laminated Timber shall be modified for in-use moisture content as set forth in the latest editions of STANDARD SPECIFICATIONS FOR STRUCTURAL GLUED LAMINATED TIMBER, AITC 117 and AITC 120.

5.5.4 Allowance for Surfacing

In applying stresses, actual sizes of finished lumber shall be used, including any necessary allowance for resurfacing.

5.5.5 Shear Deflection

When the shear deflection of an assembly having lumber flanges (such as a plywood beam) is calculated separately and added to the bending deflection, the elastic modulus of the lumber flanges may be increased 3% in calculating bending deflection.

Values for modulus of elasticity have been derived from tests which involve both bending and shear deflection, while such built-up assemblies as stressed-skin panels and box beams have such low shear stresses in the flanges that shear deflection in the flanges may be ignored. For these assemblies, therefore, the usual modulus of elasticity of the flange material may be increased to restore the portion of the deflection which is ordinarily caused by shear.

5.5.6 Radial Tension

The allowable tension stress across the grain shall be limited to one-third the allowable unit stress in horizontal shear, for southern pine and California redwood under all load conditions, and for Douglas fir and larch under wind and earthquake loadings. The limit shall be 15 psi for Douglas fir and larch for other types of load. These values are subject to modification for duration of load.

5.5.7 Radial Compression

The radial stress in compression shall not exceed the allowable stress in compression perpendicular to the grain except as modified for duration of load.

5.6 GLUED PLYWOOD END JOINTS

5.6.1 End Joints for Tension and Bending

End joints across the face grain shall be considered capable of transmitting the following stresses parallel with the face plies (normal duration of load).

5.6.1.1 Scarf Joints and Finger Joints—Scarf joints 1 in 8 or flatter shall be considered as transmitting full allowable stress in tension and flexure. Scarf joints 1 in 5 shall be considered as transmitting 75% of the allowable stress. Scarf joints steeper than 1 in 5 shall not be used. Finger joints are acceptable, at design levels supported by adequate test data.

Table 5.6.1.2. Butt Joints – Tension and Flexure

Plywood Thickness (inches)	Length of Splice Plate (inches)	Maximum Stress (psi)			
		All STRUCT. I Grades	Group 1	Group 2 and Group 3	Group 4
1/4 5/16 3/8 Sanded 3/8 Unsanded	6 8 10 12	1500	1200	1000	900
1/2	14	1500	1000	950	900
5/8 & 3/4	16	1200	800	750	700

5.6.1.2 Butt Joints—When backed with a glued plywood splice plate on one side having its grain perpendicular to the joint, of a grade and species group equal to the plywood spliced, and being no thinner than the panel itself, joints may be considered capable of transmitting tensile and flexural stresses as in Table 5.6.1.2 (normal duration of loading). Strength may be taken proportionately for shorter splice-plate lengths.

5.6.2 End Joints for Compression

End joints across the face grain may be considered as transmitting 100% of the compressive strength of the panels joined when conforming with the requirements of this Section (normal duration of load).

5.6.2.1 Scarf Joints and Finger Joints—Slope no steeper than 1 in 5.

5.6.2.2 Butt Joints—Spliced as in Section 5.6.1.2, and with the splice lengths tabulated therein. Strength may be taken proportionately for shorter splice-plate lengths.

5.6.3 End Joints for Shear

5.6.3.1 Scarf Joints and Finger Joints—Scarf joints, along or across the face grain, with slope of 1 in 8 or flatter, may be designed for 100% of the shear strength of the panels joined. Finger joints are acceptable, at design levels supported by adequate test data.

5.6.3.2 Butt Joints—Butt joints, along or across the face grain, may be designed for 100% of the strength of the panels joined when backed with a glued plywood splice plate on one side, no thinner than the panel iteself, of a grade and species group equal to the plywood spliced, and of a length equal to at least twelve times the panel thickness.

Strength may be taken proportionately for shorter splice-plate lengths.

5.6.4 Combination of Stresses

Joints subject to more than one type of stress (for example, tension and shear), or to a stress reversal (for example, tension and compression), shall be designed for the most severe case.

5.6.5 Permissible Alternate Joints

Other types of glued joints, such as tongue-and-groove joints, or those backed with lumber framing, may be used at stress levels demonstrated by acceptable tests.

5.7 GLUED LUMBER END JOINTS

5.7.1 End Joints in "Structural Glued Laminated Timber"

In "Structural Glued Laminated Timber", end joints shall comply with the requirements of U. S. Product Standard PS 56. Allowable stresses shall be those of the latest editions of STANDARD SPECIFICATIONS FOR STRUCTURAL GLUED LAMINATED TIMBER, AITC 117 and AITC 120.

5.7.2 Scarf and Finger Joints in Stress-Grade Lumber

5.7.2.1 Members Stressed Principally in Axial Tension—Slope of scarf joints shall not be steeper than 1 in 8 for dry conditions of use, nor 1 in 10 for wet conditions of use. They may then be considered to carry the full allowable tensile stress of the members glued. Finger joints are acceptable, at design levels supported by adequate test data.

5.7.2.2 Members Stressed Principally in Axial Compression—Slope of scarf joints shall not be steeper than 1 in 5 for dry conditions of use, nor 1 in 10 for wet conditions of use. They may then be considered to carry the full allowable compressive stress of the members glued. Finger joints are acceptable, at design levels supported by adequate test data.

5.7.3 Butt Joints

Butt joints may be used in stress-grade lumber tension and compression members, in which case the effective cross-sectional area shall be computed by subtracting from the cross-sectional area the area of all laminations containing butt joints at a single cross-section. In addition, laminations adjoining (actually touching) those containing butt joints and themselves containing butt joints, shall be considered only partially effective if the spacing in adjoining laminations is less than 50 times the lamination thickness. The effective area of such adjoining laminations shall be computed by multiplying their gross area by the following percentages:

Butt-Joint Spacing (t = lamination thickness)	Effective Factor
30 t	90%
20 t	80%
10 t	60%

Butt joints spaced closer than 10t shall be considered as occurring in the same section.

5.7.3.1 Tension—For butt joints in tension members or tension portions of members, the appropriate allowable stress in tension shall be multiplied by 0.8 at sections containing the joints.

5.7.4 Compression Members—End Grain Bearing

5.7.4.1 Requirements for Butt Joints—Members in compression may be butted and spliced, provided there is adequate lateral support and the end cuts are accurately squared and parallel, and maintained in tight contact.

5.7.4.2 Allowable Stresses—Allowable stresses for bearing on end grain shall be as determined from the latest edition of the NATIONAL DESIGN SPECIFICATION FOR STRESS-GRADE LUMBER AND ITS FASTENINGS, National Forest Products Association.

APPENDIX A1

GLOSSARY OF TERMS

Air-Dry Moisture Content	–	*The equilibrium moisture content of wood for conditions under cover; this condition is usually taken as 12%.*
AITC	–	*The American Institute of Timber Construction, Englewood, Colorado. A trade association responsible for promotion of, and technical information relating to glued-laminated timber.*
APA	–	*The American Plywood Association, Tacoma, Washington. A trade association organized for the purpose of quality inspection and testing of plywood production, and for doing research upon and promoting the use of plywood. Major functions are: quality testing, applied and product research, and trade promotion.*
Back	–	*The back side of a plywood panel is that side of lower veneer grade when there is a difference.*
Butt Joint	–	*A straight joint in which the interface is perpendicular to the panel face. An end butt joint is perpendicular to the grain (face grain, if plywood).*
Centers	–	*Inner layers whose grain direction runs parallel to that of the outer plies. May be of parallel-laminated plies.*
Check	–	*A lengthwise separation of wood fibers, usually extending across the rings of annual growth. Caused chiefly by strains produced in seasoning.*
Class I, II	–	*Term used to identify different species-group combinations of B-B Plyform concrete-form panels.*
Construction	–	*Trade term used to refer to the layup of a plywood panel, for example, a "4-ply construction".*
Crossband	–	*Inner layer whose grain direction runs perpendicular to that of the outer plies. Sometimes referred to as core.*
Equilibrium moisture content (also known as emc)	–	*The moisture content attained by wood when it has reached equilibrium with the surrounding atmosphere. The equilibrium moisture content of wood is highly dependent on relative humidity, but essentially independent of temperature between 32F and 100F.*
Face	–	*The face side of a panel is that side of higher veneer grade when there is a difference.*
Group or "Species group"	–	*A collection of wood species of similar stiffness and strength, classified together for convenience. Species Group 1 is the stiffest and strongest. See Section 1.5.*
Identification Index	–	*A set of numbers presented like a fraction, used in describing the capacity of sheathing grades of plywood. See Section 1.4.1.*
Inner Plies	–	*Plies other than face or back plies in a plywood panel.*
Layer	–	*A layer consists of one or more veneers laminated with grain direction parallel. Layers of plywood are oriented with the grain direction perpendicular to adjacent layers.*
Moisture Content of Wood	–	*the weight of the moisture in wood, expressed as a percentage of its oven-dry weight.*
NFPA	–	*National Forest Products Association, Washington, D.C. – a trade association of the wood industry. Maintains NATIONAL DESIGN SPECIFICATION FOR STRESS-GRADE LUMBER AND ITS FASTENINGS.*
Plugs	–	*Sound wood of various shapes, or synthetic material used to repair veneer defects.*
Ply	–	*a single thin sheet of wood in a plywood panel; a veneer.*
Repair	–	*Any patch, plug or shim placed in veneer or finished plywood panel.*

Shim – *A long narrow repair of wood or suitable synthetic not more than 3/16" wide.*

Species Group – *See "group".*

Touch-sanding – *A sizing operation consisting of a light surface sanding in a sander. Frequently affects the face only, and so assumed in the section-property calculations for this Specification.*

Veneer – *Thin sheets of wood of which plywood is made; plies.*

APPENDIX A2

MINIMUM BENDING RADII

The following radii have been found to be appropriate minimums for mill-run panels of the thickness shown, bent dry. Shorter radii can be developed by selection for bending of areas free of knots and short grain, and/or by wetting or steaming. Exterior-type plywood should be used for such wetting or steaming. Panels to be glued should be redried before gluing. The radii given are minimums, and an occasional panel may develop localized fractures at these radii.

TABLE A2

Minimum Bending Radii for Plywood Panels

Panel Thickness (inches)	Bending Radii (feet) for Panel Bent in Direction	
	Across Grain	Parallel to Grain
1/4	2	5
5/16	2	6
3/8	3	8
1/2	6	12
5/8	8	16
3/4	12	20

APPENDIX A3

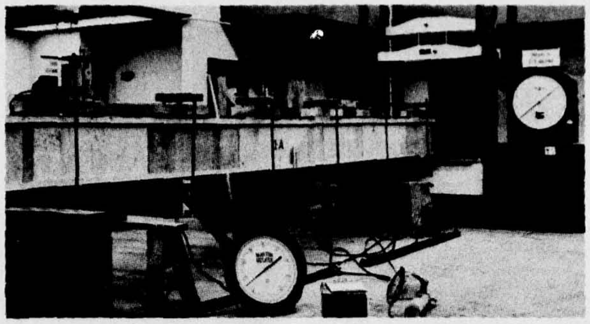
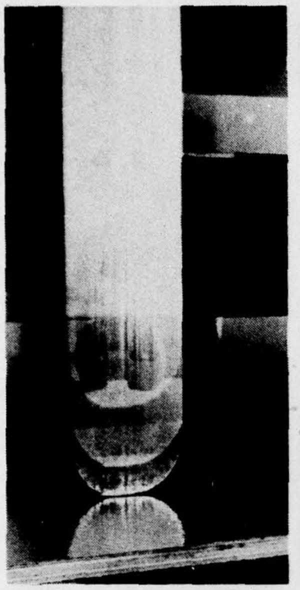
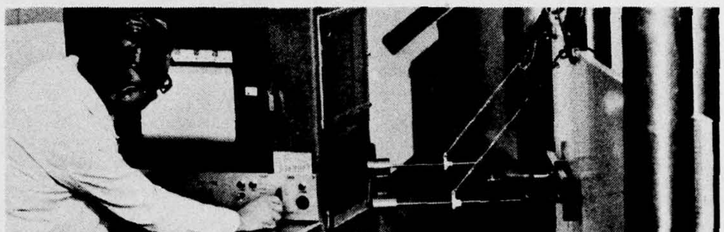
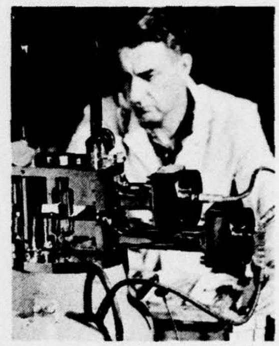
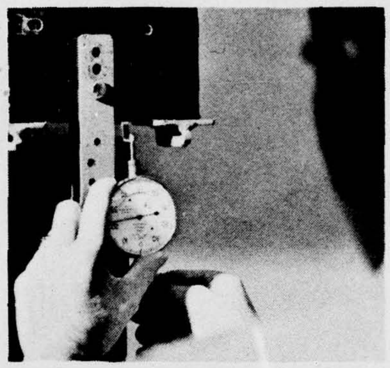
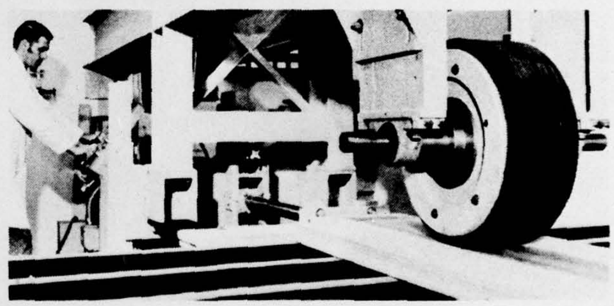
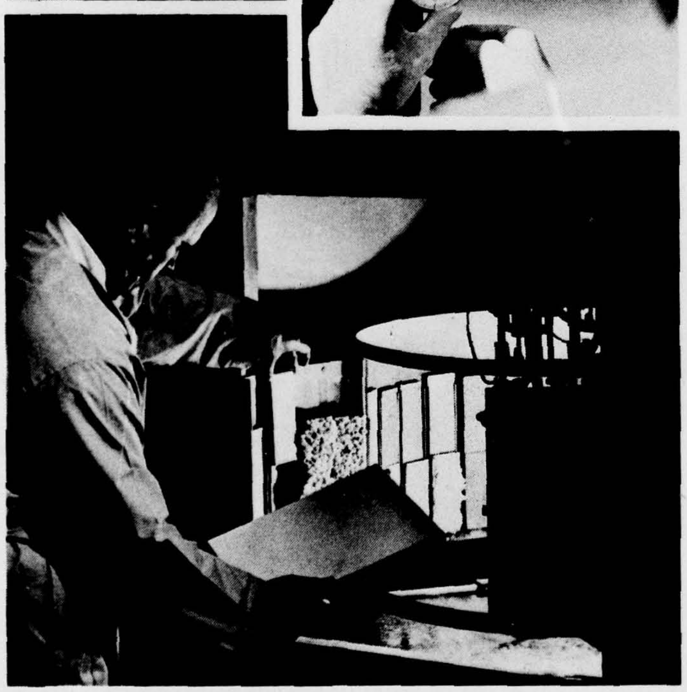
REFERENCES

I. SUPPLEMENTS TO THIS PUBLICATION

Supplement 1, DESIGN OF PLYWOOD CURVED PANELS
Supplement 2, DESIGN OF PLYWOOD BEAMS
Supplement 3, DESIGN OF PLYWOOD STRESSED-SKIN PANELS
Supplement 4, DESIGN OF PLYWOOD SANDWICH PANELS

II. REFERENCES *(listed in order of appearance)*

1. U. S. PRODUCT STANDARD PS 1 for CONSTRUCTION AND INDUSTRIAL PLYWOOD. Available from the American Plywood Association.
2. ESTABLISHING CLEAR WOOD STRENGTH VALUES. American Society for Testing and Materials Standard D 2555.
3. BENDING STRENGTH AND STIFFNESS OF PLYWOOD. U.S.D.A., Forest Products Laboratory Research Note FPL-059.
4. NATIONAL DESIGN SPECIFICATION FOR STRESS-GRADE LUMBER AND ITS FASTENINGS. *National Forest Products Association.*
5. RELATION OF STRENGTH OF WOOD TO DURATION OF LOAD. U.S.D.A., Forest Products Laboratory Research Report R-1916.
6. PLYWOOD – PRESERVATIVE TREATMENT BY PRESSURE PROCESSES. American Wood – Preserver's Association Standard C9.
7. QUALITY CONTROL PROGRAM FOR SOFTWOOD LUMBER, TIMBER AND PLYWOOD PRESSURE TREATED WITH WATER-BORNE PRESERVATIVES FOR GROUND CONTACT USE IN RESIDENTIAL AND LIGHT COMMERCIAL FOUNDATIONS. American Wood Preservers Bureau Standard AWPB FDN.
8. PLYWOOD – FIRE-RETARDANT TREATMENT BY PRESSURE PROCESSES. American Wood-Preserver's Association Standard C27.
9. PLYWOOD RIDGE BEAMS FOR MOBILE HOMES. American Plywood Association Research Report Number 124.
10. PLYWOOD FOLDED PLATES – DESIGN AND DETAILS. American Plywood Association Research Report Number 121.
11. PLYWOOD DIAPHRAGM CONSTRUCTION. Available from American Plywood Association.
12. EFFECT OF SUPPORT WIDTH ON PLYWOOD DEFLECTION. American Plywood Association Research Report Number 120.
13. FABRICATION OF PLYWOOD CURVED PANELS. American Plywood Association Fabrication Specification CP-8.
14. FABRICATION OF PLYWOOD BEAMS. American Plywood Association Fabrication Specification BB-8.
15. FABRICATION OF PLYWOOD STRESSED-SKIN PANELS. American Plywood Association Fabrication Specification SS-8.
16. FABRICATION OF PLYWOOD SANDWICH PANELS. American Plywood Association Fabrication Specification SP-61.
17. FABRICATION OF PLYWOOD FOLDED PLATES. American Plywood Association Fabrication Specification FP-69.
18. FABRICATION OF TRUSSED RAFTERS WITH PLYWOOD GUSSETS. American Plywood Association Fabrication Specification GT-8.
19. U. S. PRODUCT STANDARD PS 56 for STRUCTURAL GLUED LAMINATED TIMBER. Available from American Institute of Timber Construction.
20. STANDARD SPECIFICATIONS FOR STRUCTURAL GLUED LAMINATED TIMBER OF DOUGLAS FIR, WESTERN LARCH, SOUTHERN PINE AND CALIFORNIA REDWOOD. American Institute of Timber Construction Standard AITC 117.
21. STANDARD SPECIFICATIONS FOR STRUCTURAL GLUED LAMINATED TIMBER USING "E" RATED AND VISUALLY GRADED LUMBER OF DOUGLAS FIR, SOUTHERN PINE, HEM-FIR, AND LODGEPOLE PINE. American Institute of Timber Construction Standard AITC 120.

The APA Research Center in Tacoma, Washington, is the hub of activity directed toward proving new plywood applications and determining plywood behavior under specific conditions. Shown here are tests in progress using some of the center's extensive research facilities.

Top to bottom, right to left:

Component ultimate load testing
Impact test
Plywood bending strength test
Bond strength test
Bolt connection strength
Wheel loading
Weathering test

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